Post, S.L. and Murray, R., 2019. Effective bout widths for uniform spread of lime from ground spreaders. In: *Nutrient loss mitigations for compliance in agriculture*. (Eds L.D. Currie and C.L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 32. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 16 pages.

EFFECTIVE BOUT WIDTHS FOR UNIFORM SPREAD OF LIME FROM GROUND SPREADERS

S. L. Post[1] and R. Murray[2]

[1]Lincoln Agritech, PO Box 69133, Lincoln 7640, New Zealand
[2]Ravensdown Limited, PO Box 1049, Christchurch 8140, New Zealand.
Email: scott.post@lincolnagritech.co.nz

Abstract

There is a strong correlation between crop yields and evenness of application of lime. Lime is the most widely used fertiliser/soil conditioner product in New Zealand, but it is not very mobile in the soil, so it is important to achieve uniform application of lime. Lime is a very challenging material to spread, due to its fine particle size and its non-uniform size distribution, resulting in poor ballistic properties. Further, lime also has adhesive properties that cause it to come off the conveyer belt in discrete chunks or cakes rather than as a smooth continuous granular flow. Field testing was conducted to measure the uniformity of lime spreading over a range of application rates relevant to variable-rate application. Five different trucks were tested over application rates from 500 to 5000 kg/ha, and also at different driving speeds. Spread patterns were measured across three tray lines for each test condition, and coefficients of variation (CV) calculated as a function of bout width for each line. Measurements were also made of the particle size distribution for the lime used, and videos were taken of the lime motion in the vicinity of the spreader disks. The results of the field trials show that on average a bout width of 10 m was obtained at a coefficient of variation (CV) of 25%, and a bout width of 5 m at a CV of 10%. There was variation of lime in the longitudinal as well as the transverse direction, with a CV of 22% averaged across all trucks in the direction of truck travel. This variation is caused by the caking of the lime as it comes off the belt, which can be observed both directly and indirectly in the videos taken by the truck-mounted camera.

Keywords

Spread pattern testing, ground spreaders, variable rate application

Introduction

The economic consequences of uneven application of lime have been demonstrated by Horrell et al. (1999) and Grafton et al. (2013). There is a strong correlation between crop yields and evenness of application (at the appropriate application rate) of lime. Approximately 1.5 million tonnes of lime are spread in New Zealand each year (Statistics New Zealand, 2007), making it the most widely used fertiliser/soil conditioner product. "As lime dissolves in soil, the soluble calcium and/or magnesium does not move very far from its point of dissolution until it reacts with other soluble components or with the cation exchange complex of the soil." (Wells & Sims, 1992) Therefore uniform application of lime is even more important than for other fertilisers.

Some twin disk spreaders are Spreadmark certified for lime application, however it is not common practice. This trial aims to determine the optimum machine settings for variable rate lime application on a twin disk spreader with the assumption that swath width is governed by the results of this work – aiming at <10% CV when applying lime to arable crops. There are very few published reports on pattern testing of lime. Kondinin (2006) in Australia tested at 1500 kg/ha and 20 km/h. 0.5 m trays were tested with 0.5 m spacing between them. Table 1 shows the results from Kondinin's testing. They achieved a bout width of about 7 m with a CV of 25%. Figure 1 shows a pair of examples of their measured spread patterns.

Table 1: Lime spread at 1500 kg/ha, with bout widths at 25% CV. All but the Comspread were manual rate controllers. Kondinin, 2006.

Truck	Spinner Drive	Round & Round	Up and Back
Bredal K65	Belt	10	11
Comspread Bulk Bin	Hydraulic	6	6
Gason 7370	Hydraulic	6	6
Grizzly GM18-860	Hydraulic	5	6
Landaco TS8000	Hydraulic	7	7
Marshall 880T	Belt	7	6
Average		**6.8**	**7.0**

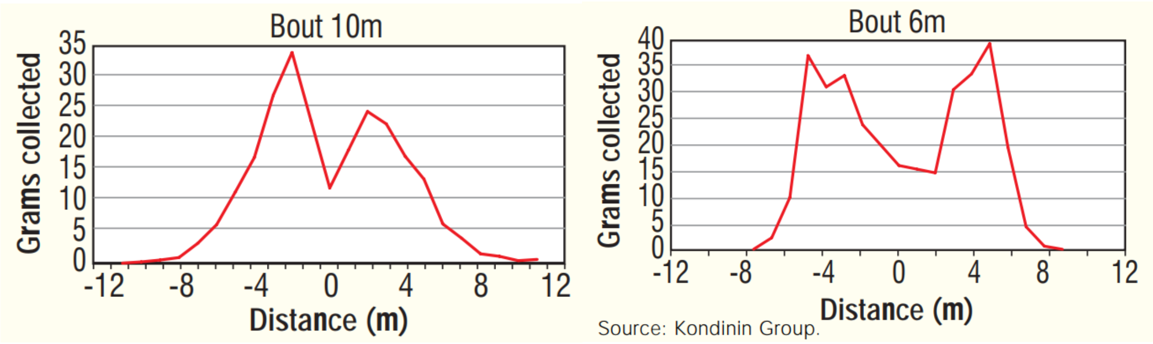

Figure 1: Example measured spread patterns for Bredal (left) and Comspread (right) trucks in Kondinin testing (2006).

Cunha & Filho (2016) in Brazil tested at 2000 kg/ha at driving speeds from 6 km/hr to 20 km/hr. (200 – 667 kg/min). The results from Cunha & Filho are shown in Table 2. It can be observed in their data that trucks with lower nominated bout widths had lower CV's. It should be noted that 3 of the 5 limestone samples they used were very fine, with 68-75% of the mass less than 425 microns. They measured both transverse and longitudinal CV's.

Table 2: Lime spread at 2000 kg/ha, from Cunha & Filho, 2016.

Truck	Moisture (%)	Speed (km/h)	Nominated bout width (m)	CV at bout width (%)	CV in longitudinal axis (%)
Hercules 24.000	6.4	5	8	17.3	23.7
Lancer Maximum 25.000	7.2	20	11	27.8	25.0
Lancer Maximum 12.000	3.3	8	8	13.9	16.9
Self-propelled Hercules 5.0	2.3	10	14	30.3	24.4
Hercules 10.000	3.5	6	9	13.5	18.6
Average			**10.0**	**20.6%**	**21.7%**

A couple of older published testing results were found. Glover and Baird (1973) tested 4 different trucks with wet dolomitic limestone at an application rate of 2,250 kg/ha. Three of the four trucks had CV's of approximately 25% at 10 m swath width, and the fourth achieved 15% CV. Alley et al. (1980) measured spread patterns for 9 different samples of dolomitic and calcitic limes, using a model 11 HGEHT twin disk spreaders with hydraulically driven spinners and a ground-driven chain, run at 16 km/h with a spinner speed of 700 RPM and application rate of 4480 kg/ha. They calculated CV's ranging from 11.7% to 20.6%, with an average of 16.1% at an effective spread swath of 9.6 m. They also noted that handling problems were observed in materials that were too fine, defined as > 60% passing a 100-mesh sieve (149 microns), corresponding with the less dense limes (around 1,300 kg/m^3). They also noted segregation of particle size along the spread width, though with fairly coarse sieving (only 4 meshes were used), noting that the coarse particles (> 840 microns) spread more evenly than the medium size ones, but the very fine particles (< 74 microns) were fairly uniform. The particle size distribution of lime is important as all of the particles less than 149 microns will react within the first year of application, while particles larger than 20 mesh (840 microns) are not expected to react within a year of application (Carey, 2006).

Materials and Methods

Table 3 shows a summary of the trucks tested. These trucks were selected to represent a range of commonly used types in New Zealand.

Table 3: Description of the five spreaders tested in this study.

Truck #	Test Date	Company	Bin Make	RPM	Description	Bout Width
J	13 Sept. 2018	Spreading Canterbury	Engineering Repairs Ltd.	800	2017 Scania. XC10	12 m
K	14 Sept. 2018	Spreading Canterbury	Bredal	800	Scania. Single belt	12 m
L	18 Sept. 2018	Mainland Spreading	Engineering Repairs Ltd	950	2018 Iveco. XC10	12 m
M	19 Sept. 2018	Mainland Spreading	Paul Hoyle Engineering	600	2014 MAN. X20 fixed gate height.	14 m
N	20 Sept. 2018	Frews Transport	Transpread	900	Twin Chain; JWE3 controller	10 m

Testing Procedure

For each test point the driver was given a specified application rate (kg/ha) and driving speed (km/h), and instructed to turn on the spreader at a sufficient distance before the test track to ensure uniform steady application across all three rows of trays. The rows of trays were aligned to be perpendicular to the prevailing winds, with the driver driving into the headwind if possible. In times of gusting wind a spotter would be positioned near the wind anemometer and signal the driver to proceed during a lull in the wind. After the test run the lime in each tray was collected. A 10-cm paint brush was used to brush the lime into a corner of the tray and pour it into a plastic cup. The plastic cups were transported in trays of 25 each, with position location marked, to be transported to the electronic scale. The mass collected in each cup was weighed in order from left to right across each row. If any of the trays were hit by the truck during the run, the tray was not measured and the mass for the tray was interpolated by the surrounding trays for the bout width analysis. Application rates of 500, 1000, 2000, 3000, 4000, and 5000 kg/ha were tested at a driving speed of 15 km/h, and the driving speed was varied at 10, 15, and 20 km/h at a constant application rate of 2000 kg/ha. With a crew of 7 people it took 30 minutes to collect and weigh the lime from each trial.

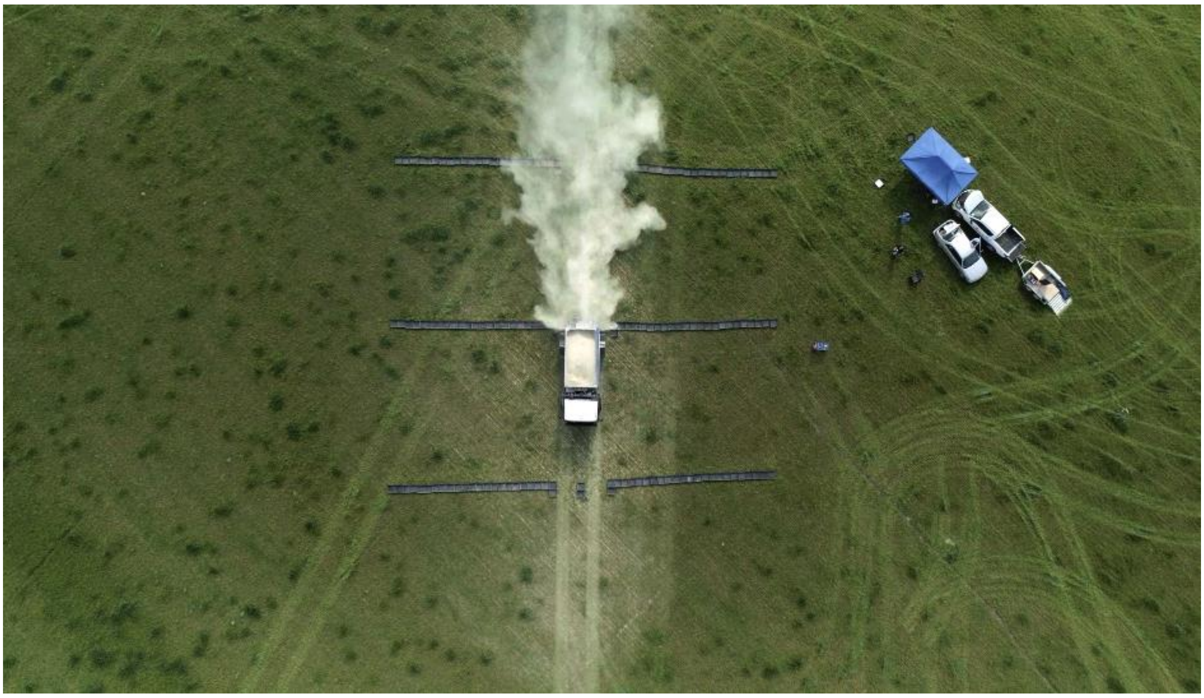

Figure 2: Overhead view of truck L during a trial, showing layout of 3 collection lines. Photo provided by Victoria O'Sullivan of Ravensdown.

Lime properties

Ravensdown Kakahu lime was used. Three of the truck operators used an assumed density of 1,300 kg/m^3 (J,K,N); the other two used 1,200 kg/m^3 (L,M). All trucks used lime from the same store at Spreading Canterbury in Southbridge. Approximately 5 tonnes was loaded on to each truck in the morning for the day of testing. Samples were taken on the first day and on the fourth day and stored in sealed containers for later sieving analysis.

Other data collected

A GoPRO Hero5 camera was attached to the back of the trucks using a high-strength suction mount when possible in an attempt to observe whether overloading of the lime onto the spinner disks occurred. Wind speed and direction were measured with a spinning cup anemometer and directional vane for each trial.

Data analysis

Software from SpreadMark tester AgCal was used to calculate CV as a function of bout width for each line of trays collected. The bout width for each of the three lines was averaged together for the results presented here.

Trial site

The trial site was located on a paddock off Beachcroft Rd. near Southbridge, Canterbury, at location 43°51'16.9"S 172°15'40.3"E.

Results and Discussion

Spreading data

Figure 3 shows an example of the collected tray masses across the three sample lines (a,b,c) for Truck L running at 15 km/h and 2000 kg/ha, and Figure 4 shows the CV values calculated for sample line ‘a’ for that trial as a function of desired bout width in the transverse direction. In a Round & Round driving pattern the right side of one pass always overlaps the left side of another, while in To & Fro driving the right side of one pass overlaps the right side of the adjacent pass. A CV value of 20.1% was calculated in the longitudinal direction across the 3 tray lines shown in Figure 3.

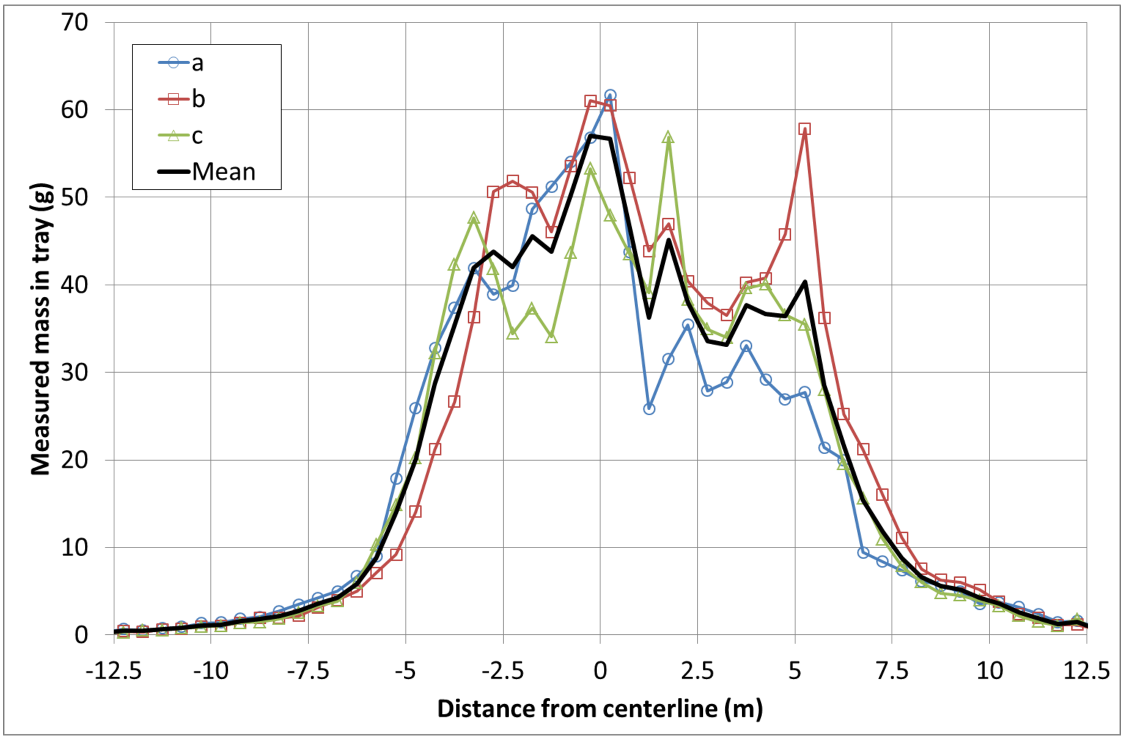

Figure 3: Measured mass collection for 3 tray lines (a,b,c) and averaged value for truck L at 2000 kg/ha and 15 km/h.

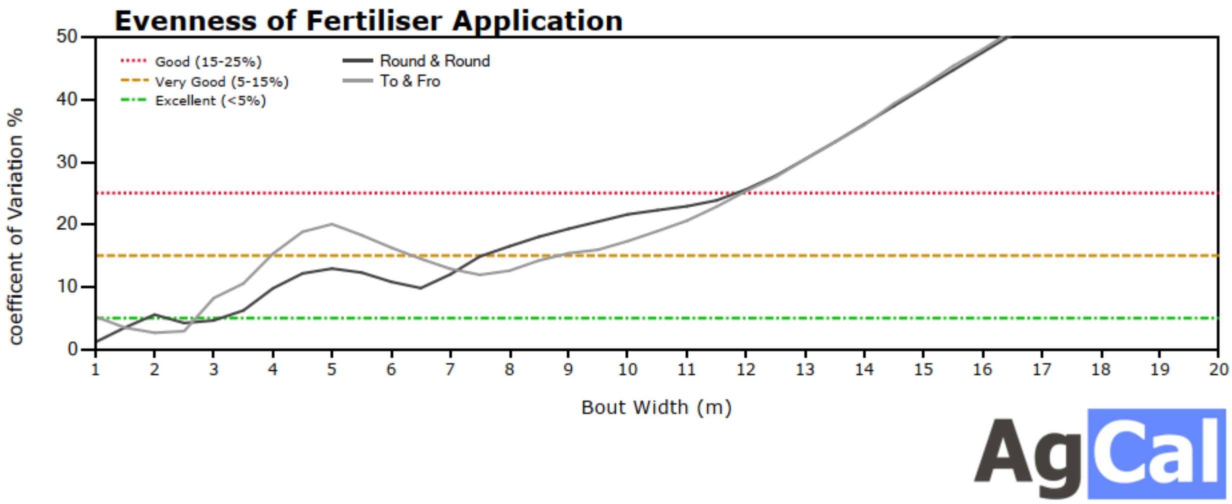

Figure 4: Plot of CV as a function of bout width for tray line 'a' from Fig. 8.

Application rate

Figures 5 & 6 show the bout widths calculated using a CV of 25%, which is the value normally used for lime, though there is no scientific basis behind that choice (Russell Horrell, personal communication). There is no clear trend of bout width as a function of application rate, though it appears to be somewhat worse at the lowest application rate of 500 kg/ha. All of the values shown in this section are arrived at by calculating the bout width for each of the three sample lines, and then averaging those three bout width values to arrive at the average values presented here.

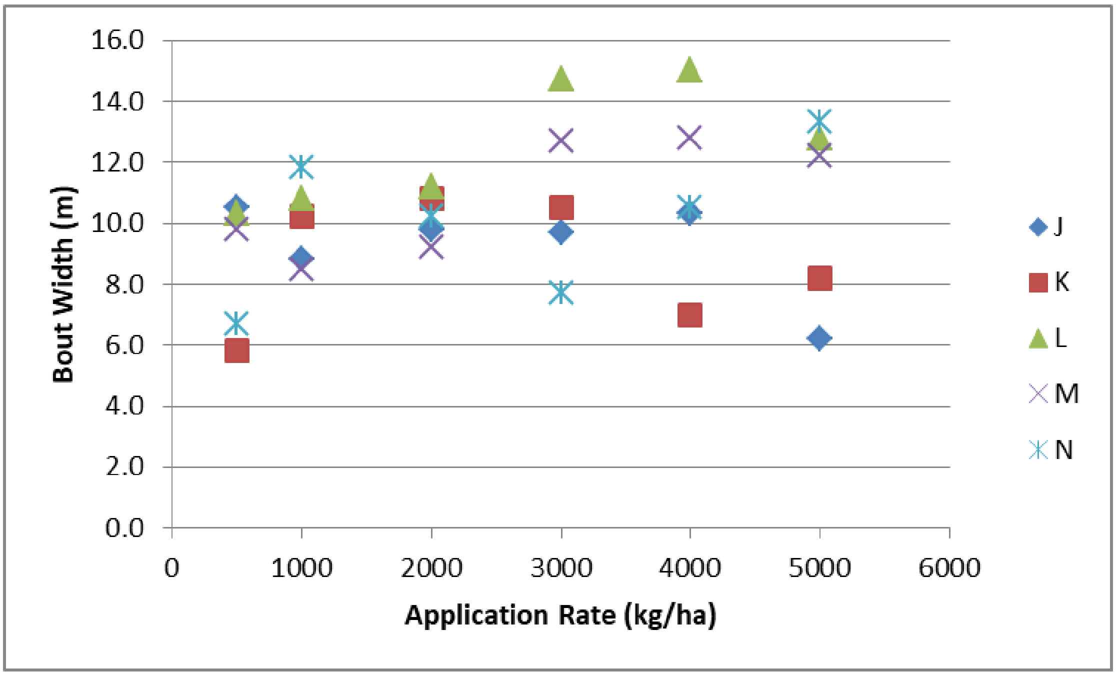

Figure 5: Calculated bout widths at 25% CV for To & Fro pattern driving.

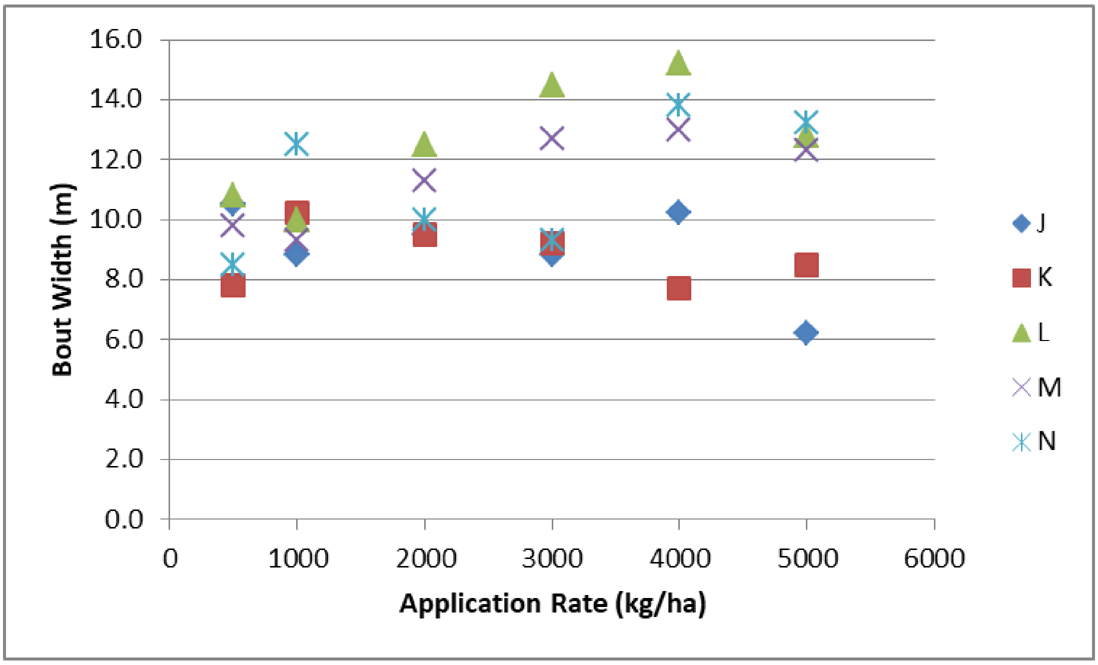

Figure 6: Calculated bout widths at 25% CV for Round & Round pattern driving.

Figures 7 & 8 and Tables 4 & 5 show the bout widths calculated using a CV of 10%.

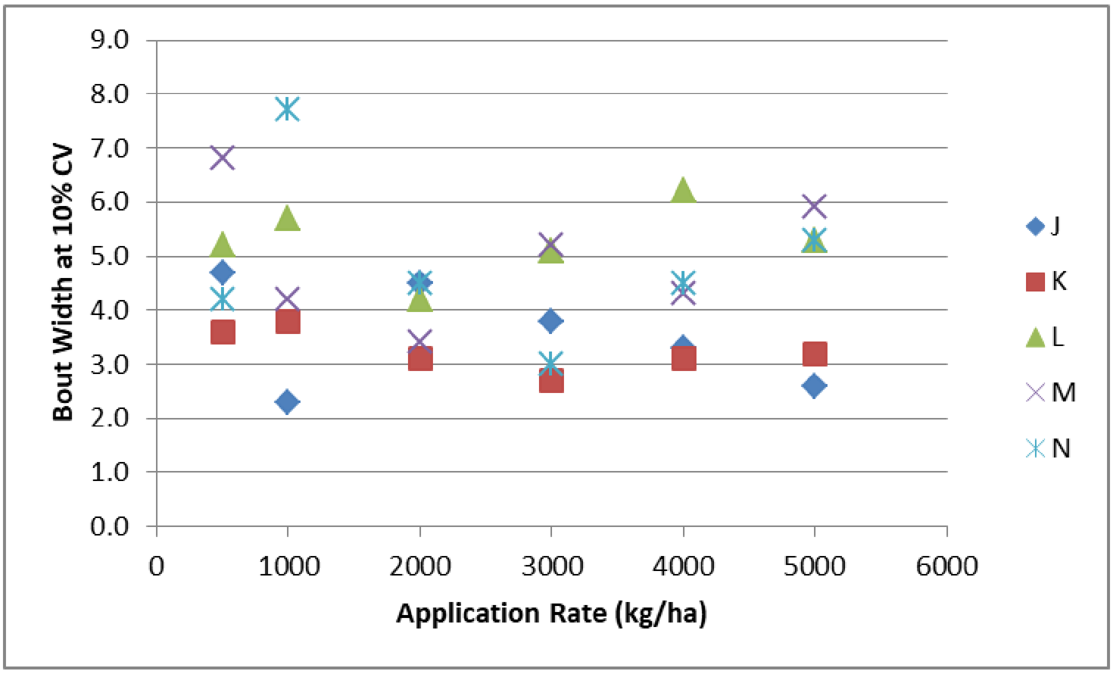

Figure 7: Calculated bout widths at 10% CV for To & Fro pattern driving

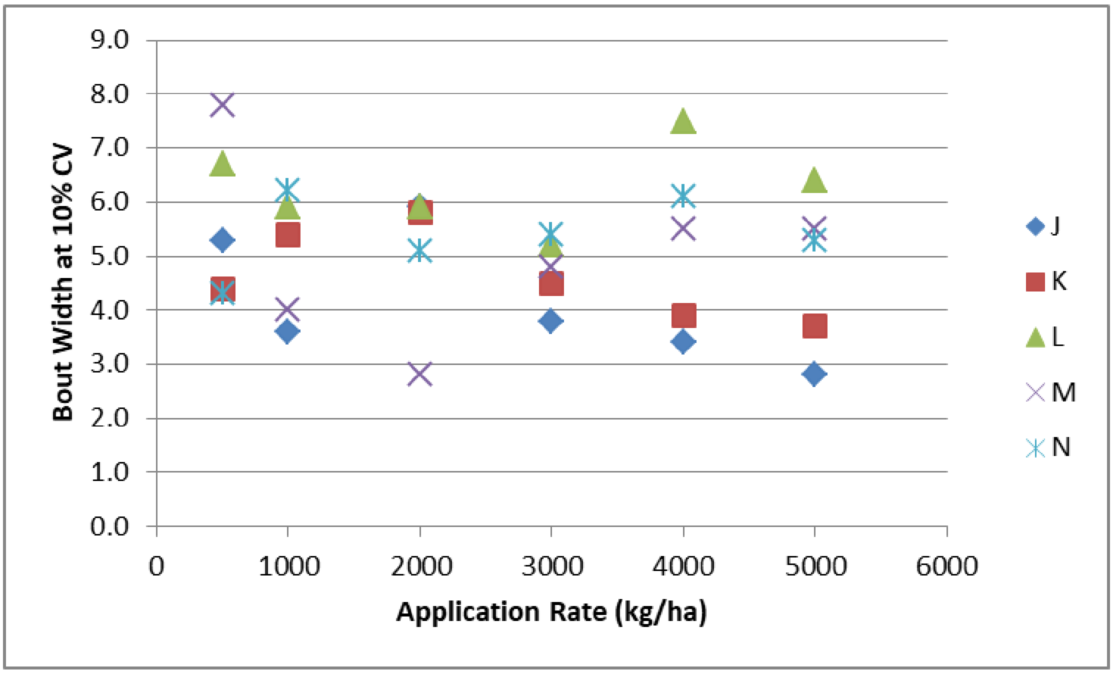

Figure 8: Calculated bout widths at 10% CV for Round & Round pattern driving

Table 4: Tabular values of calculated bout widths shown in Fig. 12 at 10% CV for To & Fro pattern driving at 15 km/h.

Rate (kg/ha)	J	K	L	M	N	Average
500	4.7	3.6	5.2	6.8	4.2	4.9
1000	2.3	3.8	5.7	4.2	7.7	4.7
2000	4.5	3.1	4.2	3.4	4.5	3.9
3000	3.8	2.7	5.1	5.2	3.0	4.0
4000	3.3	3.1	6.2	4.3	4.5	4.3
5000	2.6	3.2	5.3	5.9	5.3	4.5
Average	3.5	3.3	5.3	5.0	4.9	4.4

Table 5: Tabular values of calculated bout widths shown in Fig. 13 at 10% CV for Round & Round pattern driving at 15 km/h.

Rate (kg/ha)	J	K	L	M	N	Average
500	5.3	4.4	6.7	7.8	4.3	5.7
1000	3.6	5.4	5.9	4.0	6.2	5.0
2000	5.9	5.8	5.9	2.8	5.1	5.1
3000	3.8	4.5	5.2	4.8	5.4	4.7
4000	3.4	3.9	7.5	5.5	6.1	5.3
5000	2.8	3.7	6.4	5.5	5.3	4.7
Average	4.1	4.6	6.3	5.1	5.4	5.1

Alternatively, it is possible to calculate a bout width by first averaging the mass distributions from the three lines for each trial and then calculating a bout width for the "averaged" measured mass distribution. The bout widths calculated in this manner are shown in Tables 6 and 7 for 10% CV. While this does produce more favorable bout width values, it does not account for the variation in the longitudinal direction (direction of truck travel) of the spread patterns. There were often appreciable differences in mass across the three lines, which appeared to correlate with "puffing" seen in the lime coming off the truck, which in turn is caused by the lime coming off the belt in large cakes, similar to iceberg calving, before it hits the spinners. An average coefficient of variation in the longitudinal direction across the bout width for each truck at the 2000 kg/ha, 15 km/h driving condition was calculated, with values of 24.7%, 18.8%, 17.7%, 15.1%, and 33.7% for trucks J, K, L, M, and N, respectively.

Table 6: Calculated bout widths at 10% CV for To & Fro pattern driving at 15 km/h. Bout width calculated by first averaging the mass collected in all three tray lines, and calculating the bout width for the "averaged" tray line.

Rate (kg/ha)	J	K	L	M	N	Average
500	6.5	4.2	7.8	8.3	3.8	6.1
1000	2.3	5.3	9.0	4.1	9.5	6.0
2000	7.9	3.2	7.5	4.9	12.0	7.1
3000	2.8	2.7	7.2	5.3	3.0	4.2
4000	3.3	3.8	4.4	5.0	3.4	4.0
5000	2.7	3.7	4.5	9.5	11.5	6.4
Average	4.3	3.8	6.7	6.2	7.2	5.6

Table 7: Calculated bout widths at 10% CV for Round & Round pattern driving at 15 km/h. Bout width calculated by first averaging the mass collected in all three tray lines, and calculating the bout width for the "averaged" tray line.

Rate (kg/ha)	J	K	L	M	N	Average
500	6.5	4.5	9.5	8.3	5.9	6.9
1000	3.8	5.5	7.0	4.9	6.3	5.5
2000	8.0	6.0	6.8	4.7	12.0	7.5
3000	3.0	4.4	7.7	5.2	6.0	5.3
4000	3.3	7.0	8.1	5.8	6.4	6.1
5000	2.9	3.7	8.2	11.3	6.2	6.5
Average	4.6	5.2	7.9	6.7	7.1	6.3

Driving speed

The effects of driving speed on bout width are shown in Tables 8 and 9. Overall there is not much difference between 10 and 15 km/h, while the fastest tested driving speed of 20 km/h shows some improvement in bout width.

Table 8: Bout widths as a function of driving speed for 25% CV at 2000 kg/ha

Speed km/h	Truck K	L	M	N	T&F Ave.
10	9.2	12.3	11.7	11.0	**11.1**
15	10.8	11.2	9.2	10.2	**10.4**
20	10.8	14.0	13.5	13.5	**13.0**
Ave.	10.3	12.5	11.5	11.6	

Speed km/h	Truck K	L	M	N	R&R Ave.
10	8.7	12.7	11.7	9.5	**10.7**
15	9.5	12.5	11.3	10.0	**10.8**
20	11.0	13.8	13.3	13.5	**12.9**
Ave.	9.7	13.0	12.1	11.0	

Table 9: Bout widths as a function of driving speed for 10% CV at 2000 kg/ha

Speed km/h	K	Truck L	M	N	T&F Ave.
10	3.5	5.2	3.4	3.5	**3.9**
15	3.1	4.2	3.4	4.5	**3.8**
20	2.7	6.0	4.1	4.4	**4.3**
Ave.	3.1	5.1	3.6	4.1	

Speed km/h	K	Truck L	M	N	R&R Ave.
10	6.0	8.0	3.8	5.1	**5.7**
15	5.8	5.9	2.8	4.8	**4.8**
20	5.2	7.3	4.8	5.4	**5.7**
Ave.	5.7	7.1	3.8	5.1	

Applied mass

The calculated deposited applied mass is shown in Figure 9 vs. the intended applied mass. It can be seen that most trucks slightly under-applied, and truck K was unable to deliver rates above 3000 kg/ha. Table 10 shows the variation in collected mass across each of the three sample lines for each spreader and application rate.

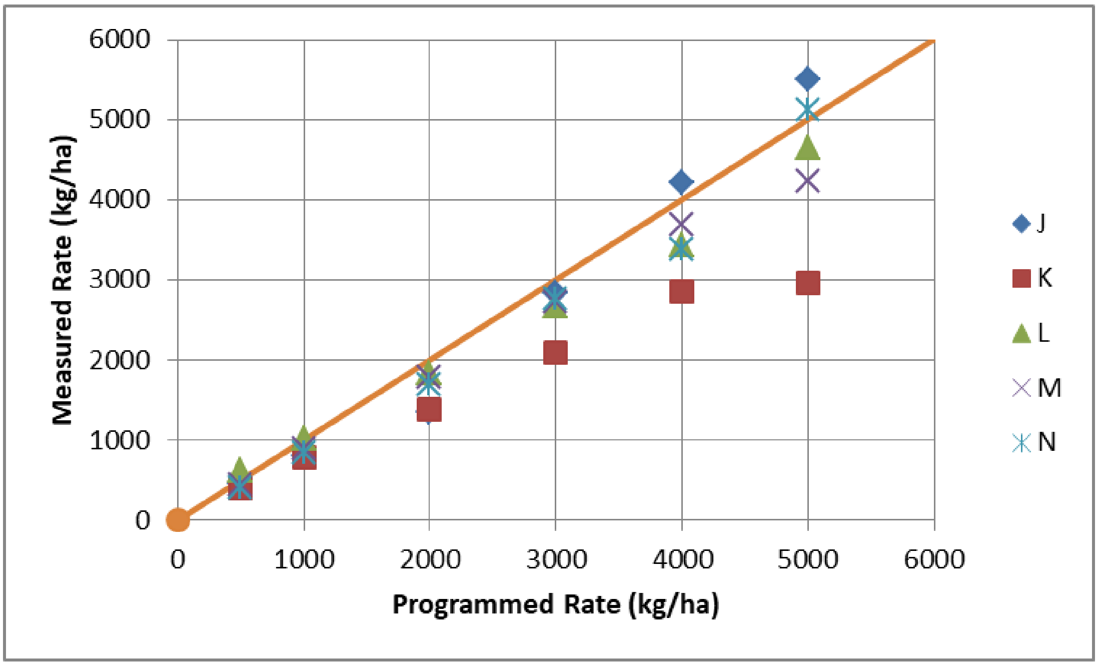

Figure 9: Measured deposited mass vs. computer-input applied rate, averaged across all three tray lines.

Table 10: Variation in collected mass across each of the three tray lines for each trial.

Set Rate (kg/ha)	Tray Line	Measured application rate for each spreader (kg/ha)				
		J	**K**	**L**	**M**	**N**
500	a	606	428	763	446	364
	b	366	392	590	456	403
	c	388	364	497	407	442
	average	**453**	**395**	**617**	**436**	**403**
1000	a	403	704	900	962	770
	b	1203	846	908	925	852
	c	796	781	1242	802	867
	average	**801**	**777**	**1017**	**896**	**830**
2000	a	1518	1222	1732	1871	1961
	b	1162	1352	1976	1774	1419
	c	1376	1557	1778	1709	1704
	average	**1352**	**1377**	**1829**	**1785**	**1695**
3000	a	2599	1933	2815	2935	2852
	b	3451	2174	2674	2697	2711
	c	2453	2171	2503	2524	2731
	average	**2834**	**2093**	**2664**	**2719**	**2765**
4000	a	3814	2995	3504	3594	2776
	b	4125	2854	3549	3726	3693
	c	4705	2720	3235	3754	3690
	average	**4215**	**2856**	**3429**	**3691**	**3386**
5000	a	5076	2732	4475	4354	5270
	b	5270	3086	5149	4355	5350
	c	6146	3089	4316	3993	4750
	average	**5497**	**2969**	**4647**	**4234**	**5123**
Average of set (%)		91	71	97	89	88

Sieving data
The total mass collected after sieving was 99.5% of the mass poured into the sieve tower, indicating no significant errors due to loss of mass in the testing. A stack of 11 Endicott sieve trays plus the pan was used for the size analysis. All samples were shaken for at least 5 minutes prior to measuring the mass in each cylinder.

The Size Guide Number (SGN) is an estimate of the median granule size in a fertiliser. To calculate SGN the sieve opening (in unit of mm) that retains (or passes) 50% of the weight of a fertiliser sample is determined and then multiplied by 100. SGN is a mass median diameter. So for example, a SGN of 50 corresponds to a median size of 0.5 mm = 500 microns, so that half of the mass of the fertiliser would pass through the 500 micron size sieve. The Uniformity Index (UI) is inversely proportional to the width of the particle size distribution. The higher the value of UI the more uniform the particle sizes, and lower values of UI indicate a greater range of particles sizes. It is calculated by taking the size of the sieve opening that retains 95% of the sample mass and dividing by the size of the sieve opening that retains 10% of the sample mass, and multiplying by 100. A value of UI = 100 would indicate all the particles had exactly the same size.

For the sample taken from the first day of the first week of testing, the size guide number (SGN) was 13, and the Uniformity Index (UI) was 2.27. The bulk density of the sample was measured as 1.22 kg/L, with a tap density of 1.41 kg/L, with a resulting compressibility index of 15.5%, indicating reasonable flowability. 96.1% of the mass passed the 2.0 mm sieve and 71.2% passed the 0.5 mm sieve, compared to Ravensdown specifications of at least 95% of the mass passing the 2.0 mm sieve and at least 50% passing the 0.5 mm sieve. 40% of the mass was contained in very fine particles, less than 125 microns. For the sample taken from the second week of testing, the SGN was 16 and UI was 3.46, with 94.8% passing the 2.0 mm sieve and 66.9% passing the 0.5 mm sieve, and 35% less than 125 microns, indicating there was no significant change in the lime properties across the five trucks tested.

For comparison, the measurements of Praat and Moorhead in 2004 for a sample from the same quarry reported values of SGN = 20 and UI = 1.75, 38% of the mass less than 125 microns, with a bulk density of 1.17 kg/L, indicating the lime used in the present testing was finer than that from 14 years ago. Praat and Moorhead tested 18 samples from across New Zealand, with SGN ranging from 16 to 62 and UI from 0.89 to 6.34. Thus the lime used in this study can be considered as having the finest particle size distribution likely to be seen in use in New Zealand.

Table 11: Mass fraction retained on each sieve in the measurement stack.

Sieve opening size (mm)	Day 1 sample	Day 4 Sample
2.00	3.9%	5.2%
1.40	4.3%	5.2%
1.00	4.2%	4.7%
0.710	5.0%	6.0%
0.500	11.4%	12.1%
0.355	5.0%	4.9%
0.250	9.5%	9.1%
0.180	7.5%	7.2%
0.125	9.6%	10.4%
0.090	14.6%	15.6%
0.063	9.1%	10.8%
0.0	15.8%	8.9%

Variation across spread width

Samples were collected from across one side of the spread pattern to look for segregation of lime by particle size along the spread width. Samples were consolidated from groups of 5 adjacent trays, covering 2.5 m in width, in order to obtain a large enough sample for sieve analysis. Even at this sample width, the outermost sample was still only 10 g. Alley et al. (1980) grouped samples in 1.2 m widths to analyse the spatial pattern of particle size segregation.

As can be seen in Table 12, the larger particles, which have more ballistic kinetic energy when leaving the spinner disks, tend to be found further away from the spreader centerline. This was also seen qualitatively when collecting the samples in the field. The innermost section has a large number of small particles, which have poor ballistic properties and do not travel far from the spinner disks. There were a significant number of fine particles (less than 125 microns) collected at all widths, believed to be from the large cloud of lime dust behind the spreader truck that travels above the truck height and eventually settles to the ground.

The importance of the segregation of particle size across the spread pattern to its efficacy in the field will depend on the bout width used, as to how much overlap there is between the different parts of the pattern. At wider bout widths there will be some areas where the overlap is from the outer edges of the spread patterns of both passes of the spreader, and thus mostly containing only large particles, while for narrower bout widths there will be enough overlap between the different sections of the spread pattern to provide a more uniform particle size distribution.

Table 12: Fraction of mass retained for each sieve tray, as a function of distance along the spread width. Sample taken from trial at 2,500 kg/ha, 15 km/h, Truck J, from the left side of tray row 'c'. Distances are from truck centerline.

Sieve Size (mm)	outer 10-12.5 m	mid-out 7.5-10m	middle 5.0-7.5 m	mid-in 2.5-5.0 m	inner 0-2.5 m	Overall
2.000	24.8%	23.5%	6.6%	3.2%	2.7%	3.9%
1.400	3.0%	20.5%	9.1%	3.6%	2.9%	4.3%
1.000	0.0%	6.0%	10.3%	5.1%	3.2%	4.2%
0.710	0.0%	0.9%	9.6%	7.3%	3.6%	5.0%
0.500	0.0%	0.0%	10.3%	18.8%	8.1%	11.4%
0.355	0.0%	0.4%	4.1%	10.0%	6.3%	5.0%
0.250	2.0%	0.4%	6.7%	13.8%	12.4%	9.5%
0.180	0.0%	0.0%	5.3%	9.1%	10.7%	7.5%
0.125	1.0%	1.7%	8.5%	7.9%	11.7%	9.6%
0.090	7.9%	8.1%	10.5%	7.2%	13.7%	14.6%
0.063	19.8%	13.2%	8.0%	5.4%	11.8%	9.1%
0.000	41.6%	25.2%	11.0%	8.6%	12.8%	15.8%
Total mass (g)	10.1	23.4	113.0	180.0	271.4	100%

Video analysis

A suitable location could not be found on all trucks to mount the GoPro Camera to view the lime motion onto the spinner disks. Quality videos were obtained for 3 of the trucks (K, M, N). Only on truck N were we able to find an angle that allowed viewing the fall of the lime onto the disks from the belt. In Figure 10, frames 844 and 1860 show the effects of the iceberg calving mechanism of the lime leaving the belt in large cakes rather than as a continuous granular flow as it falls onto the disks. The mass hitting the spinners is not a constant in time, but fluctuates as each cake comes off, and this also changes the location of impact of the lime on the spinners as a function of time, which affects performance.

Figure 10: Image captures from video file # 0544. of truck N, showing calving of lime. Spinner rotating clockwise.

Conclusions

Lime is a very challenging material to spread, due to its fine particle size and its non-uniform size distribution, resulting in poor ballistic properties. Further, lime also has adhesive properties that cause it to come off the conveyer belt in discrete chunks or cakes rather than as a smooth continuous granular flow. Spreader trucks are design optimised for high-value products such as urea which have larger and more uniform particle sizes. There are a number of spreader settings (gate height, belt speed, driving speed, spinner speed) that can be adjusted to give the optimum spread pattern, though the combination of settings that give the optimum pattern at one spreading rate may not be the same at a different spreading rate, or with a different lime (particle size distribution), and of course with a different spreader machine. While there has been work in New Zealand and internationally on understanding the ballistics of fertiliser flow off the disk, there still does not exist a computer model to predict the flow of fertiliser on spinning disks, so this optimisation would have to be done empirically.

The study of lime spreading rates for bout widths of 25% CV was consistent with the few previous published studies, with bout widths of approximately 10 m. No previous study examined lime bout widths for 10% CV. For this study it was calculated at approximately 5 m. There was variation of lime in the longitudinal as well as the transverse direction, with a CV of 22% averaged across all trucks in the direction of truck travel. This variation is caused by the caking of the lime as it comes off the belt, which can be observed both directly and indirectly in the videos taken by the truck-mounted camera. There were also some indications that use of a lower gate height resulted in a better spread pattern and bout width, but as this was not a design variable, but rather a result of operator and controller settings, no definitive conclusions can be drawn.

The spreaders were tested in the “as presented” condition. Optimising the disc speed, gate height, belt/chain speed, and forward speed for each desired flow rate, may result in higher bout widths @ 10% CV. There would likely be a different combination of settings that gives the best spread pattern at low (500 kg/ha) and high (5000 kg/ha) spread rates, so in practice this would require creating a “map” of spreader settings to be used at each flow rate for a given model of spreader that could be input into the computer controller. A Spreadmark test for a granulated material like urea does not necessarily tell how a spreader will spread fine powder like lime. Getting a Spreadmark test on lime, particularly the lime that the operator will most commonly use, is needed to ensure the spreader will give a good result with lime. It is also recommended to use dry lime to avoid caking issues as it comes off the belt. Achieving more uniform application of lime will require an investment, either in better equipment, time spent optimising that equipment, more passes at a smaller bout width, or in a lime product that spreads better.

Acknowledgements

This research was funded by Ravensdown and FAR. Russell Horrell contributed to the planning, testing, and data analysis.

References

Alley, M. M., McCart, G. D., Wolf, D. D., & Smith, E. S. (1980). Particle Size Effects on Stockpiling and Spreading Agricultural Limestone 1. *Soil Science Society of America Journal*, 44(2), 438-440.

Carey, P., Ketterings, Q., & Hunter, M. (2006) Liming Materials. Cornell University Agronomy Fact Sheet Series, #7.

Cunha, J. P., & Filho, R. S. (2016). Broadcast distribution uniformity of fertiliser with centrifugal spreaders used in variable rate application. *Engenharia Agrícola*, 36(5), 928-937.

Glover, J. W., & Baird, J. V. (1973). Performance of spinner type fertiliser spreaders. *Transactions of the ASAE*, 16(1), 48-0051.

Grafton, M. C. E., Yule, I. J., & Manning, M. J. (2013). A review of the economic impact of high levels of variance in fertiliser spreading systems. In *Proceedings of the New Zealand Grassland Association* (Vol. 75, pp. 131-136).

Horrell, R., Metherell, A. K., Ford, S., & Doscher, C. (1999). Fertiliser evenness-losses and costs: a study on the economic benefits of uniform applications of fertiliser. In *Proceedings of the Conference-New Zealand Grassland Association* (pp. 215-220).

Kondinin Group (2006) Research Report: "Tests spread news on accuracy" Farming Ahead No. 175 August 2006 pp. 18-36.

Praat, J.-P., & Moorhead, B. (2004) Flowability Properties of Lime for Agricultural Aircraft. Report for CAA.

The Spreadmark Code of Practice for the Placement of Fertiliser in New Zealand. Feb. 2015.

Wells, K, & Sims, J. (1992) Factors Affecting Crop Response to Liming. University of Kentucky Department of Agronomy, Soil Science News & Views, Vol. 13, No. 3.