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ADOPTION OF PRECISION AGRICULTURE  
TECHNOLOGIES FOR FERTILISER PLACEMENT IN  
NEW ZEALAND

A thesis presented in partial fulfilment of the requirements of the degree of

Doctor of Philosophy

in

Agricultural Engineering

at Massey University, Palmerston North, New Zealand



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2007

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## ABSTRACT

Major agronomic and economic losses are caused by inaccurate application of nutrients from ground based spreading vehicles. These losses come from both over and under application of fertiliser resulting from such practices as driving at inappropriate bout widths. This work reviewed current spreader testing procedures; compared the performance of international test methodologies and evaluated the use of a digital image processing program to perform spreader testing. Methods to evaluate field performance were developed; this analysis of field application was used to calculate the economic effect of using precision agricultural technologies in New Zealand dairy farming systems.

A matrix of fourteen hundred 0.5 x 0.5 m fertiliser collection trays was used to evaluate individual test methodologies. Results indicated that there were major variations in calculated certifiable bout width between different methods and direct comparison should be avoided. Tray layout within  $\pm 5$  m of the centre spread line had the largest effect on calculated bout width whilst methods that incorporated rows of trays in the longitudinal direction were less variable compared to those using a single transverse test. The probability too accurately assign bout widths using different international test methods was analysed, the ACCU Spread (Australia) test method had the highest level of confidence in its bout width calculation followed by the ES (Europe) test method. The ISO(i) (World), ISO(ii) (World) and Spreadmark (NZ) tests were all found to be comparable to one another whilst the ASAE (USA) method had the lowest level of confidence in its bout width calculation because of wide collector tray spacing.

A method to extract a wider range of data from spreader tests using a hybrid image processing system was developed. Results indicated that there was a strong relationship between two dimensional particle area and particle mass under laboratory ( $R^2 = 0.991$ ) and field ( $R^2 = 0.988$ ) conditions.

Although transverse spreader tests provided a good indication of machine performance, they did not account for the interaction of the spreader and its operational environment. A method was developed that used the vehicle location during field application and the transverse spread pattern represented as polygons to create field application maps. Initial results showed large variations compared to the measured transverse spread pattern. A wider study over 102 paddocks on four dairy farms showed that average variation was 37.9%. An improvement to the field application method discussed is given; this tool used the geographical

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position, heading angle and a series of static spread pattern tests from the spreading vehicle to achieve greater accuracy in field measurements.

The described field application methods were used to assess the ability to execute a nutrient plan using both actual and optimised spreading data collected during field application. A loss of \$66.18 ha<sup>-1</sup> was calculated when comparing the efficiency of using current spreading methods to those assumed in nutrient budgeting practice. If a guidance and control system were used correctly to provide optimised field application the loss could be reduced to \$46.41 ha<sup>-1</sup>.

This work highlighted the difficulties in achieving accurate field nutrient application; however, by developing the ability to quantify field performance, economic opportunities could be evaluated. Overall, this work found that there was a strong agronomic and economic case for the implementation of precision agricultural technologies in the New Zealand fertiliser industry. However, the current range of equipment used by the spreading industry would have difficulty in delivering these benefits.

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## ACKNOWLEDGEMENTS

My sincere thanks go to my chief supervisor, Dr. Ian J. Yule for his supervision, guidance, and practical advice on how to approach technical issues throughout this study, and to my co supervisors, Dr. Jim R. Jones and Professor Mike J. Hedley for their advice, constructive suggestions and critical comments throughout.

I would also like to thank everyone involved in the New Zealand Centre for Precision Agriculture, for technical assistance, providing many memorable moments and generally keeping me sane throughout the duration of the study. In particular Potscrub, Mr Pat, Little Johnny Two Pies, Mork, Yuley, MT, Johnno and Woody.

My special thanks are extended to Dr. Hilton Furness and Mr. Greg Sneath from FertResearch for liaising with fertiliser industry contributors ensuring the research could be applied at industry level. I also thank the Fertiliser Quality Council, Ravensdown and Ballance Agri-Nutrients for providing technical data and support.

I particularly appreciated the financial assistance from an Enterprise Scholarship in conjunction with New Zealand Fertiliser Manufacturers' Research Association (NZFMRA) for my study. Also a Claude McCarthy Fellowship and A Royal Society travel grant which aided me to travel to overseas conferences.

Finally my immense gratitude to my parents for supporting me in my agricultural endeavours, and my partner Alecia, for her love, encouragement and support during my PhD study.

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## CHAPTER 1

### GENERAL INFORMATION

#### *1.1. INTRODUCTION*

The adoption of available fertiliser spreading technology is based on the assumption that current spreading performance is adequate; it is recognised in New Zealand and around the world that this is not the case. The successful and accurate application of fertiliser is extremely important to New Zealand agriculture. Studies from around the world demonstrate that it is both economically wasteful and environmentally damaging to have inaccurate and uneven spreading. In recent years there have been increasing efforts to ensure the accurate and even spreading of fertiliser on New Zealand farms. The result of this has been the development of a number of quality assurance programs including: The Code of Practice for Fertiliser Use in New Zealand (NZFMRA, 2002); the Fertmark quality assurance program (NZFQC, 2002); and the Spreadmark quality assurance program (NZFQC, 2006). These documents are based on legislation in the Resource Management Act (1991) and the Agricultural Compounds and Veterinary Remedies Act. There is great debate within industry as to whether the developed legislation is appropriate in terms of the range and application of the testing procedures, the level of accuracy and the extent to which test results can be achieved in the field. Additional scientific work was required to give improved statistical analysis of data as well as developing statistically sound testing methods. There is also the need to develop additional test elements to ensure consistent performance during field application of fertilisers on New Zealand farms.

#### *1.2. NEW ZEALAND FERTILISER INDUSTRY*

Over four million tonnes of fertiliser are spread in New Zealand annually (Statistics New Zealand, 2002) with a cost to consumers of over \$648 million. Fertiliser is spread in many forms. The main sources are: urea, diammonium phosphate (DAP), ammonium sulphate, Lime, Phosphatic fertilisers and Potassic fertilisers. Effluent from collection ponds is also spread as a form of nutrient enrichment for soils.

Most of the fertiliser spread in New Zealand is lime (42%), this is followed by phosphatic fertilisers (30%), potassic fertilisers (9%) and Urea (8%) (Table 1.1). However, lime only accounts for 5% of the total

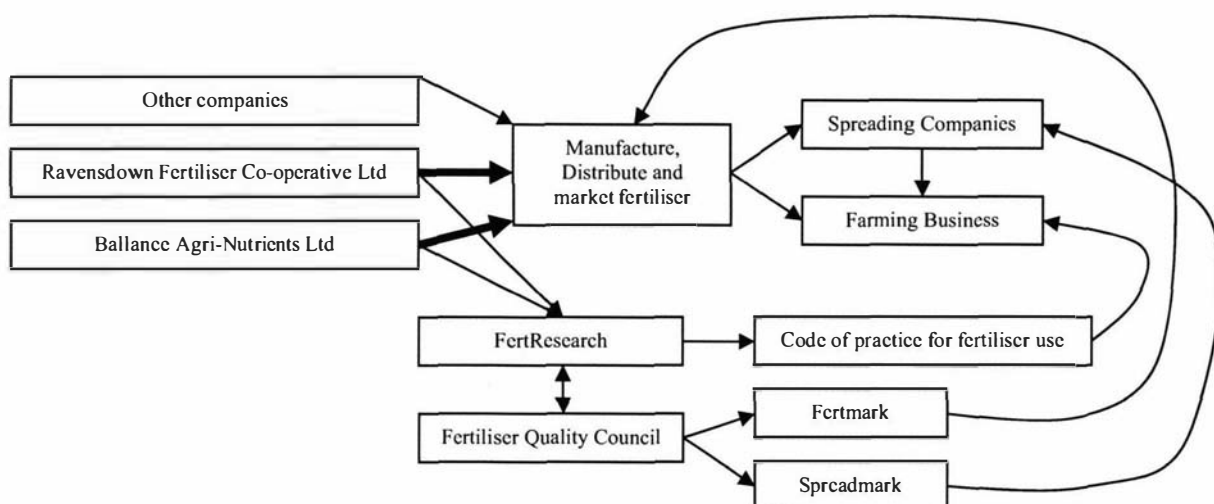
value of fertiliser spread. Higher value fertilisers such as phosphatic fertilisers (29%), potassic fertilisers (19%), urea (19%) and DAP (13%) make up most of the total fertiliser value spread annually for agricultural production (Table 1.1.).

**Table 2.1. Quantity and value of common fertilisers spread annually in New Zealand for agricultural activities.**

	Urea	DAP	Ammonium sulphate	Other N fertilisers	Lime	Phosphatic fertilisers	Potassic fertilisers
Total Spread/yr (T)*	314,354	182,958	43,546	229,243	1,773,753	1,232,196	359,676
\$/tonne**	\$395	\$457	\$240	\$364	\$17	\$158	\$339
Total Valuc/yr	\$124,169,830	\$83,611,806	\$10,451,040	\$83,444,452	\$30,153,801	\$194,686,968	\$121,930,164

\* Fertiliser Use, 2002 Agricultural Production census, Statistics New Zealand.  
\*\* Ravensdown Co-operative Ltd, November 2003.

The New Zealand fertiliser industry is dominated by two major manufacturers, Ravensdown Fertiliser Co-operative Ltd and Ballance Agri-Nutrients Ltd. Together these two companies manufacture, distribute and market fertiliser to approximately 90-95% of the New Zealand market. These two co-operative companies are predominantly farmer owned. FertResearch is the association that represents these two major fertiliser co-operatives in terms of research, development, and quality assurance. FertResearch aims to promote and encourage the responsible use of fertiliser, to maximise the benefits of fertiliser use to agriculture and to help create wealth for the New Zealand economy.



**Figure 1.1. Flow of information and processes of individual groups linked to the New Zealand fertiliser industry and their interaction.**

Because fertiliser is a vital component of New Zealand's agricultural industry, there are many structures in place to implement acceptable manufacture, spreading and use of fertiliser. The main fertiliser industry control programs that have a major bearing on fertiliser use in New Zealand include the Agricultural Compounds and Veterinary Remedies Act (1997), the Code of Practice for Fertiliser Use (NZFMRA, 2002) and the Fertmark (NZFQC, 2002) and Spreadmark (NZFQC, 2006) quality assurance programs. The linkages between these documents and industry contributors are given in Figure 1.1.

*The Agricultural Compounds and Veterinary Remedies Act* – This act replaces the fertiliser Act (1982). The current act no longer uses the word 'fertiliser' rather agricultural compound. There are three main purposes of the act all relating strongly to the use of fertiliser; these are: (a) prevent or manage risks associated with the use of agricultural compounds; (b) ensure that the use of agricultural compounds does not result in breaches of domestic food residue standards; and (c) ensure the provision of sufficient consumer information about agricultural compounds used in the production process.

*Code of Practice for Fertiliser use* – This document extrapolates on the recommendations outlined in the Resource Management Act (1991). The Resource Management Act (1991) says that everyone has a duty to avoid, remedy or mitigate any adverse effects their activities may have on the environment. The code of practice is designed to provide a procedure to enable fertiliser users to employ sustainable practices specific to their situation (i.e. farm, orchard, forest), while ensuring they fulfil their responsibility under the RMA and assist and improve the farm business decision making process required to maintain viability in today's climate of economic uncertainty (NZFMRA, 2002).

*Fertmark* – As part of the Agricultural Compounds and Veterinary Remedies Act controlled by the Ministry of Agriculture and Fisheries (MAF), fertilisers were registered and randomly tested with relation to their registered components to ensure consumers were getting what was intended. In 1991 MAF withdrew from auditing and this culminated in the Federated Farmers association responding to a lack of industry regulation and developing the Fertmark scheme; in 1996 Fertmark become its own entity. The Fertmark scheme allows primary producers of fertilisers to register their products to ensure they are promoted as quality

assured. Fertmark accredited fertilisers ensure that consumer's get the correct level of nutrient enrichment required.

*Spreadmark* - The Spreadmark quality assurance program was established by the New Zealand Groundspread Fertiliser Association in 1994 to establish greater accuracy in the methods used for applying fertiliser. The program has now expanded to include The Federated Farmers association, FertResearch and fertiliser companies. This group is governed by the Fertiliser Quality Council of New Zealand. The objective of the scheme is to provide assurance that fertilisers are been placed in locations where they can be of the most agricultural benefit and the least environmental harm. Spreadmark is used to complement the Fertmark scheme to ensure that fertiliser is manufactured, mixed and applied to ensure economic and environmental sustainability.

### ***1.3. PRECISION AGRICULTURAL TECHNIQUES IN FERTILISER APPLICATION***

Work in precision agriculture has often highlighted a surprising range of yield data from single paddocks. A ratio of 3 to 1 is not uncommon (Yule & Crooks, 1996, Yule et al., 2005). Technology is available that can be used to match fertiliser inputs to the requirements of individual areas within a field through the use of positioning systems and variable rate technologies. Because different zones within a field have different growth potential, adjusted nutrient requirements can be calculated. There is often a range of responses that are truly site specific, fertiliser application is optimised for the physiological needs of the plant, the economics of the situation in respect to the value and cost of production and the environment in ensuring that the optimal quantity of nutrients that can be utilised are applied. However, although variable rate technologies have been demonstrated to operate satisfactorily the actual basic performance of the fertiliser spreading machinery is often shown to be inadequate, poorly understood and sometimes lacking in responsiveness to changes in fertiliser demand. There is a considerable danger in adopting an over-riding technology if the basic performance of the machinery is not at an adequate level. There is concern that given the current level of performance of the national fleet of fertiliser spreaders run by both farmers and ground spreading contractors, further progress to using precision agriculture methods could be of limited value if the basics are not in place and sound test methods established.

#### **1.4. IMPROVEMENT OPPORTUNITIES**

Fertiliser is one of the main agricultural inputs in New Zealand; over four million tonnes are spread annually. It is known from overseas studies as well as work in New Zealand that the cost of poor spreader performance and operation is potentially large. Yule and Crooks (1996) gave an estimate of an annual loss of £56M (156M NZD) to the UK farming industry resulting from fertiliser application errors. Horrell et al. (1999) quantified the losses in a number of New Zealand scenarios as being approximately \$155M NZD. They went further and identified the levels of inaccuracy in spreading needed to trigger significant economic loss. In cropping systems a loss of \$20 ha<sup>-1</sup> was deemed to be significant when examining a number of different crops. Some crops had a significant economic loss even at variation levels considered to be generally acceptable and within current standards. Clearly, the higher the value of the crop the more critical the fertiliser application accuracy. However, there are also huge opportunities to improve the utilisation of fertiliser within the pastoral sectors of the New Zealand economy. Initial work by Yule et al. (2005) indicated a three fold difference in the utilisation of late spring Nitrogen fertiliser within single paddocks. This signifies a large economic and agronomic opportunity for improvement of fertiliser use in pastoral grazing systems. Pastoral farming is New Zealand's strength and it is where most of fertiliser is used. However, because returns from cropping systems have tended to be higher than pasture on a per hectare basis, little research has been conducted on fertiliser application to pastures with contrast to fertiliser application on cropped land.

The benefits of improving fertiliser application performance through the greater use of technology fall on a number of parties: fertiliser producers; groundspreaders and farmers. A 5% improvement in fertiliser utilisation would result in an annual reduction in fertiliser use of 200,000 tonnes in New Zealand. Clearly even small incremental changes in the efficiency with which fertiliser is used over the whole country will have significant economic and environmental benefits, benefits which the adoption of precision agricultural technologies could provide.

### ***1.5. AIMS OF STUDY***

The results of this study will be to give guidance as to the current use of standards employed to measure variability in fertiliser application. This work will require statistical analysis of the performance of fertiliser spreaders to be addressed. The study will also investigate the use of precision technologies in terms of adoption in pastoral farming industries. Methods to quantify field performance and economic opportunities will be evaluated. Overall, this work will enable all fertiliser manufacturers, ground spreaders and farmers to make informed decisions of the adoption of precision agricultural technologies within the New Zealand agricultural industry.

### ***1.6. STRUCTURE OF THESIS***

This thesis is based on a series of seven papers submitted to both New Zealand and international scientific journals in order to fulfil the aims of the study. Individual chapters are introduced and discussed briefly below. Each chapter has its own introduction, review of literature, results, discussion and conclusion in order to stand alone as an individual scientific paper. Each of the papers is co-authored representing my contribution and that of my supervisors where appropriate, as is conventional in science publications.

*Chapter 1* – Chapter 1 serves as an overview and introduction to the topic of study (specific literature reviews can be found in each chapter). A background into the current position of the New Zealand fertiliser industry is given and quality assurance programs currently used are discussed. Discussion is developed on how precision agricultural technologies could be used to improve current application technology techniques and from this, aims for the study are developed.

*Chapter 2* – Simultaneous transverse spreader pattern tests were conducted to investigate the statistical differences between six international test methods. A review of each test method was conducted, large differences in tray layout, tray design, number of passes performed and number of products used were found. A matrix of 1400 fertiliser collector trays, each 0.5 m by 0.5 m was used to conduct spread tests, each different international test method could be extracted from the tray matrix. A statistical simulation was performed using @RISK (Palisade, 2004) to calculate the expected variation in swath widths when using the

different methods.

*Chapter 3* – A further statistical analysis was performed on the 1400 fertiliser collector tray matrix (same dataset as chapter 2) to evaluate the statistical differences between tray masses when using different international test methods. A method to calculate whether a near neighbour effect exists between adjacent trays in the longitudinal direction of travel is also described. The work also assessed the probability of various international test methods to accurately assign bout widths for spreading vehicles.

*Chapter 4* – Alternative methods to current tray testing techniques for analysing fertiliser distribution patterns have been well documented. Many required mathematical models to calculate, rather than measure the distribution pattern from a fertiliser spreader (Aphale et al., 2003; Cunningham & Chao, 1967; Griffis et al., 1983; Olieslagers et al., 1996; Patterson & Reece, 1962; Pitt et al., 1995). However, these methods were often found to be inaccurate when compared to actual spreader test results. In this chapter a review of alternative methods for tray testing was performed and from this, a hybrid image processing method developed to analyse individual fertiliser particles landing on a collection tray. An analysis of both laboratory and field trials is given and compared to results obtained using traditional tray testing techniques.

*Chapter 5* – A preliminary investigation was conducted to test the hypothesis that field variation of fertiliser application was greater than that expressed by transverse testing. Two methods were developed to measure and compare the effect of spread pattern, driving accuracy and driving method on field variation in rectangular and triangular shaped paddocks. Coefficient of variation (CV) of field application was analysed and discussion developed with regard to the economic and agronomic consequences of poor nutrient application

*Chapter 6* – Based on preliminary results and proof of concept experiments into measuring field application variation (Chapter 5), a robust method was developed to process multiple data sets. The method used readily available information including the GPS track log and transverse distribution pattern from the tested spreader. An experimental analysis was performed to calculate application variation over a wide

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sample. Spreader tracking data was collected when applying urea on four farms within a three day period using the same driver and spreading vehicle. A “Hot spot” analysis technique was also integrated into the method to identify areas receiving statistically significant high and low application rates ( $\sigma < 2.0$ ).

*Chapter 7* – An advance on the method described in chapter 6 is given. This was required to evaluate application variability when machine parameters such as disc speed ( $\text{rev min}^{-1}$ ) and flow rate ( $\text{kg s}^{-1}$ ) were varied. This chapter describes the technical calculations to be performed at each spreader location to determine the tray mass at 0.5 m over the entire field. A brief discussion is also given with regard to reducing field application variation through the use of optimised start/stop positions of the spreading vehicle.

*Chapter 8* – Firm nutrient budgeting structures are currently available to calculate nutrient requirements of a farming system. This chapter assessed the ability to implement a nutrient budget over a twelve month period on farm using current and optimised (using guidance and control systems) spreading techniques. The methods developed in chapters 5, 6 and 7 were used to measure nutrient application accuracy. An economic analysis of production loss for the two application methods (current and optimised) were compared to theoretical nutrient application values where perfect spreading was assumed. Other economic data including the break even cost of implementing guidance and control systems on spreading vehicles is also discussed.

*Chapter 9* – The results from this thesis are summarised and future direction for studies in the field of adopting precision agricultural technologies in fertiliser application systems are given. An overview of how knowledge from this thesis was disseminated is also conveyed.

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## CHAPTER 2

# A STATISTICAL ANALYSIS OF INTERNATIONAL TEST METHODS USED FOR ANALYSING SPREADER PERFORMANCE

### *Paper Reference<sup>1</sup>*

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Lawrence, H. G., I. J. Yule, J.R. Jones. (2006). A statistical analysis of international test methods used for analysing spreader performance. *New Zealand Journal of Agricultural Research* 49: 451–463.

*Received 6 April 2006; accepted 20 September 2006*

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***Abstract** There are a number of tray testing methods used throughout the world to assess the distribution accuracy of fertiliser spreaders, all of which calculate differences in distribution pattern. The main objective of this work was to perform a statistical analysis of the differences between methods. The effect of variations in calculated bout width due to change in distribution pattern was investigated. Six international test methods were compared simultaneously using a matrix of 1400 trays, each 0.5 m by 0.5 m. Each test method could be extracted from the tray matrix. Urea fertiliser (46% N) was used for all tests at three application rates, 80, 100 and 150 kg ha<sup>-1</sup>. A simulation model created in @RISK was used to predict certifiable bout widths from each test method using overall spread pattern characteristics and statistics. Results indicated that there were major variations in calculated certifiable bout width using the different methods. Tray layout within  $\pm 5$  m of the spread line had the biggest effect on calculated bout width. Method designs that incorporated trays in the longitudinal direction were more accurate in predicting the average variation than when a single transverse test was used. In conclusion, if comparison is required between two or more spreaders, the same test method and tray layout should be used. Having a sufficient concentration of trays within  $\pm 5$  m of the center of the distribution pattern will describe the behaviour of a spreader with greater accuracy.*

***Keywords.** Centrifugal fertiliser spreading; fertiliser spreader testing; spread pattern statistics; precision agriculture.*

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<sup>1</sup> This chapter contains some changes to the published paper resulting from examiner emendations.

## 2.1. INTRODUCTION

Fertiliser spreader performance has traditionally been assessed through the use of trays placed across the path of a spreader as it travels along the field or in a testing hall. There is a number of test systems worldwide which vary slightly in their layout, including the number of trays used, tray size and tray spacing.

The aim of this study was to examine the output accuracy of various test methods providing a statistical description of their results. The analysis aimed to investigate the effect of tray numbers in each row to see if significant differences in calculated certifiable bout width occurred. A single transverse test using standard tray layouts was compared to using multiple transverse tests.

Six test methods were used as part of this study, these include the ISO standard (i) , ISO standard (ii) , ASAE standard S341.2, (ASAE, 1999), European standard (CEN, 1999), Accu-Spread (AFSA, 2001) in Australia and Spreadmark (NZFQC, 2006) in New Zealand. Most of these test methods used 0.5 m diameter trays organised in a single transverse row to capture the spread pattern of the spreader. Only one test method (Accu-Spread) relies on more than one row during a test. No account is taken of the longitudinal variation between individual rows when multiple tests are carried out. The results of the test are given as the bout width where the coefficient of variation (CV) does not exceed a specified level. The CV is determined by taking the dividing the standard deviation by the mean when the spread pattern is overlapped at one metre intervals. In all cases the maximum allowable CV is 15% for nitrogenous fertilisers and 25% where low analysis fertilisers are used. The test methods are compared in Table 2.1.

**Table 2.1. Variations in transverse measurement methods of various spreader testing programs used throughout the world**

Standard	Tray Size	Tray Frequency	Transverse Spacing
(i) ISO Standard (World)	0.5 m x 0.5 m	Enough to cover total distributing width	Continuous
(ii) ISO Standard (World)	1.0 m x 2.5 m	Enough to cover total distributing width	Continuous
ASAE S341.3 (USA)	>0.3 m, but <10% of the swath width	10 per swath	Uniform spacing
ES (Europe)	0.5 m x 0.5 m	224 per 56 m (2 rows fixed)	Continuous
Accu-Spread (Aus)	0.5 m x 0.5 m	50 (2 rows 50 m apart)	Continuous
Spreadmark (NZ)	0.5 m x 0.5 m	60 per 30 m	Continuous

All fertiliser spreader testing programs or standards aim to achieve the same goal, uniform distribution of nutrients where they provide the most efficient economic and agronomic use for both the contractor and the farmer. There are currently two internationally recognised standards (International Standards Organisation and American Society of Agricultural Engineers) for testing the uniformity of broadcast spreaders and three quality assurance programs (Spreadmark (New Zealand), Accu-Spread (Australia), European Standard (ES)) operated throughout the world. All testing programs and standards differ in their methodology for measuring the uniformity of fertiliser distribution. The differences can be split into six main areas, these being, testing facilities, test products, application rates, testing conditions, tray collectors and measurement standards.

*Testing facilities* - Testing venues are either inside or outside. Both Spreadmark and the ES prefer tests to be performed inside, however they do allow outdoor tests to be undertaken by negotiation. The Accu-spread program allows outdoor testing and the ISO(i), ISO(ii) and ASAE standards do not differentiate between indoor and outdoor testing. There are advantages and disadvantages for testing in either indoors or outdoors. Outdoor testing facilities are more representative of what performance is achievable in the field, however indoor tests allow the best achievable results to be obtained. Both Spreadmark and the ES specify minimum indoor requirements as being >25 by 45 m and 80 by 60 m respectively. Other factors to consider regarding the testing facilities include slope, wind, surface and antibounce protection. Parish & Bergeron (1991) found that material bouncing from the surface into collection pans can have a significant effect on pattern results. Concurring with this, both ISO standards (i & ii) and Spreadmark require some type of antibounce material to be on the ground to avoid particles bouncing into trays. Typically, on concrete surfaces lime is used as it is relatively cheap and easy to obtain. In outdoor tests, antibounce is not a significant issue as most tests are performed on pasture which absorbs particle energy much more readily than solid surfaces (e.g. concrete). The influence of wind on particle distribution is also considered when testing spreader performance, the ISO (i & ii), ASAE and Accu-Spread methodologies require wind speed to be below 2, 2.2 and 2.78 m s<sup>-1</sup> respectively during a test. Although the ES and Spreadmark testing protocols do not specify a limit, wind speed must be recorded.

*Test products and application rates* - Different fertilisers have different physical characteristics, which affect spread distribution patterns. A spreader should be able to be adjusted to spread a number of different fertiliser products. The number of products required to be tested in order to comply with test constraints ranges from one to six. Both the ASAE standard and Accu-Spread test protocols require only one product to be tested, the Spreadmark and ISO(i) and ISO(ii) protocols use three fertilisers whilst the ES protocol requires six types of fertiliser to be tested. The target application rate also varies between testing protocols. The ASAE and Spreadmark tests recommend the 'typical' or 'average' applied rate for the product, whereas the Accu-Spread program requires a minimum of 600 kg ha<sup>-1</sup> to be applied from a number of passes without weighing in between. This was often thought to influence results by material being blown out of collection trays. However, Parish (1999) concluded from a study that multiple passes for spreader pattern testing did not disturb the material in the trays from previous passes. The ES standard requires separate application rates for each product tested (18 passes), whilst the ISO(i & ii) standards states application rates of 600, 400 and 150 kg ha<sup>-1</sup> for powdered, granular and prilled fertilisers respectively. A number of physical particle characteristics of the fertiliser are required to be measured such as uniformity index (UI) and size guide number (SGN). The evenness of the spread pattern depends to a large extent on the physical properties of the fertiliser (Csizmazia, 2000). Physical particle measures include: particle size, moisture content, bulk density, particle density, granular hardness, particle shape, surface texture and angle of repose. The measurement of some of these attributes can be completed in the field and used as the basis to adjust machine settings both between and within products. However, others such as surface texture and angle of repose require specialised measurement techniques, and therefore are usually only measured during spreader tests.

*Equipment testing conditions* - The condition and setup of spreading equipment tested can have a significant impact on spread pattern test results. The ES and ISO(i & ii) protocols indicate that the machine is to be setup in accordance with manufacture's instruction without being optimised. This is important during type testing to get comparability between the same models to ensure that the design performs according to specification. The purpose of type testing is to ensure that satisfactory spreader performance can be achieved over an appropriate range of fertilisers and application rates, and that spreaders have reasonably stable operating characteristics over small variations in fertiliser characteristics (NZFQC, 2002). Because the ASAE,

Accu-Spread and Spreadmark tests are measuring single machines, protocol recommends that they are in sound working order and set up for the product being spread. The load of fertiliser put into the hopper varies with different tests, however no statistical data on how hopper load effects distribution pattern could be found. A small volume of fertiliser in the hopper during testing could produce abnormal feed onto the discs creating variation in distribution pattern. For this reason all tests specify a volume of fertiliser required in the hopper to perform tests.

**Table 2.2. Physical characteristics of urea fertiliser used in all tests.**

Physical indices	Test sample	Optimal range*
Bulk Density ( $t\ m^{-3}$ )	0.84	0.8 – 0.9
Mean particle size (mm)	3.4	2.9 – 3.4
Size guide number	340	250 – 350
Uniformity index	59	20 – 60

\* As determined by Fertmark code of practice (NZFQC, 2002)

## 2.2. MATERIALS AND METHODS

Transverse and longitudinal pattern tests were carried out on a centrifugal spreader to evaluate the performance of the testing methods at three spread rates using urea fertiliser (46% N). The urea used for all testing was acquired from a local Manawatu bulk store. The physical characteristics of the urea were analysed prior to spreading (Table 2.2). Results indicated that the urea used for testing was within the range set by New Zealand Fertmark standards (NZFQC, 2002) for the product. The three target application rates were 80, 100 and 150  $kg\ ha^{-1}$ , these were deemed as typical target rates by the spreader operator. Different application rates were achieved by adjusting the flow of fertiliser onto the spinning discs. The Spreadmark protocol (NZFQC, 2006) was used as the basis for the test procedures. The spreader used to conduct all tests was a Transpread W chain twin spinner on a Mercedes truck unit. The spreader had an inbuilt computer control system which adjusted the flow rate of fertiliser onto the disc in real time in order to maintain a constant application rate ( $kg\ ha^{-1}$ ) with variations in forward speed ( $km\ hr^{-1}$ ). The machine settings were the same as those used during field spreading of urea, and a spinner disc speed of 750 rpm was used for all tests. A disc speed of 750 rpm allowed the same spreading width to be achieved at all application rates. The machine had been previously

certified to spread at the bout width of 17 m at an application rate of  $100 \text{ kg ha}^{-1}$  of Urea. The hopper size of the unit was 10 tonne. A load of 200 kg of urea was placed at the rear of the spreader covering the feed mechanism and was sufficient to produce normal flow as required by Spreadmark ((NZFQC, 2006) protocol. Tests were conducted on a flat tarsealed surface. Wind speed was measured using an electronic anemometer which recorded wind speed and direction directly to a field computer every 1 S.

Fourteen hundred collector trays were laid out edge to edge forming an 80 by 18 tray matrix (Figure 2.1) This tray matrix allowed 18 simultaneous tests to be conducted. Four columns of trays were removed from the collection area to allow the spreading unit to pass over the trays. The collection trays used were fabricated according to Spreadmark Standards . The trays measured 0.5 m wide, 0.5 m long and 0.15 m high and were made of 4 mm thick plastic. A cardboard divider was placed inside each tray to reduce particle energy on impact and reduce the number of particles bouncing out of the collection tray. Wind speed was monitored during all experiments to ensure that the specified maximum wind speed was not exceeded ( $<2 \text{ m s}^{-1}$  to conform to all test methods).



**Figure 2.1. 1400 Tray matrix used to collect 18 simultaneous transverse tests on a Transpread W twin chain spreader.**

The performance of the spreader was evaluated using the six standard test methods described in Table 2.2 (ISO(i), ISO(ii), ASAE, ES, Accu-Spread and Spreadmark). The tray layout for the ISO(i) and Spreadmark tests were identical and therefore gave the same result, this is referred to as the ISO(i)/Spreadmark test in

future text. The ASAE method gave broad layout guidelines (Table 2.2); therefore the two extremities of allowable limits were used. In future text the ASAE method is represented by the ASAE (4 m) and ASAE (0.5 m) tests referring to the tray dimensions of 4.0 by 4.0 m and 0.5 by 0.5 m respectively. The 1400 collector tray matrix was used to perform each of the test designs. The bout width at the appropriate CV was compared, as was the range in possible CV for the 18 simultaneous tests. The CV for a measured transverse spread pattern is commonly used to ascertain an acceptable bout width for a spreading vehicle. The CV is calculated by overlapping the transverse distribution pattern at different bout widths; the mean and standard deviation of the overlapped application rate is calculated and this information is then used to determine the CV at different bout widths using the equation:

$$CV = \frac{\sigma}{\mu}$$

$CV$  = Coefficient of variation<sup>2</sup> (%)

$\sigma$  = Standard deviation of overlapped spread pattern

$\mu$  = Mean of overlapped spread pattern

Each test was repeated at the three application rates; this meant a total of 36 transverse tests at each application rate were analysed. Because a number of tests were being carried out simultaneously, the variable nature of the spreader's performance was observed. This allowed fundamental statistics to be calculated in order to analyse the confidence limits for each of the test methods. It was also possible to compare a wider range of test strategies, the intention being to develop the most accurate test method.

Statistics for each test method were used to simulate achievable bout width from the tested spreader using @RISK (Palisade, 2004). @RISK uses Monte Carlo simulation to show many possible outcomes in a project – and tells how likely they are to occur (Palisade, 2004). One thousand iterations were run on each method at the three test rates (80, 100, and 150 kg ha<sup>-1</sup>). Cumulative probability functions were calculated for each method at each rate, probability distributions was also calculated for all combined test data at each rate.

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<sup>2</sup> This definition is an industry rather than a statistical measure of variability. The equation above is in the published paper but should more correctly defined by equation 5 (chapter 3 and is the equation used by @RISK).

### 2.3. RESULTS

*Measuring the Spread pattern* - The spreader tested (Transpread 'W' chain twin spreader) varied in its spread pattern shape at different application rates. Spread pattern shape is commonly described by four specified shapes (triangular, oval, flattop and square). Figure 2.2 shows the average distribution pattern of 36 transverse tests derived from the six different international test methods (Table 2.2). Figure 2.2a shows the spread pattern at 80 kg ha<sup>-1</sup>, this follows the shape of a triangular shaped spread pattern. This spread pattern peaks in the centre at a maximum application rate of 115 kg ha<sup>-1</sup>. In contrast to this, the spreader when applying 100 kg ha<sup>-1</sup> (Figure 2.2b) had a lower maximum application rate (95 kg ha<sup>-1</sup>) and fitted the category of a flattop spread pattern. At a target application rate of 150 kg ha<sup>-1</sup> there is a much higher peak at the centre line (240 kg ha<sup>-1</sup>) therefore portraying a triangular spread pattern rather than that of a flattop as occurred when applying 100 kg ha<sup>-1</sup>. For all application rates the maximum spread distance of the product was ±15 m from the centre line; this was expected, as the same product and spinner speed (750 rpm) was used for each replicated test.

Figure 2.2 shows how the different tray layouts used in international test methods represented the spread pattern at the three application rates (80 kg ha<sup>-1</sup>, 100 kg ha<sup>-1</sup> and 150 kg ha<sup>-1</sup>) when using the same data set from the 1400 tray matrix (Figure 2.1). The data from the 1400 tray matrix was used to simulate each of the testing methods with an average transverse distribution pattern calculated from the 36 replications at each application rate. The actual application rates, when not overlapped, were lower than the nominal application rates due to poor calibration by the spreader operator in the feed chain onto the discs of the spreader. The nominal values will be referred to in the remaining chapters.

Figure 2.2 shows how variation beyond 5 m from the spreading vehicle is limited. However, significant transverse variation was found in the centre of the distribution patterns between the testing methods at all three rates. Table 2.3 shows that within 5 m of the spreader the standard deviation between methods was 5.44, 3.83 and 13.49 kg ha<sup>-1</sup> at 80, 100 and 150 kg ha<sup>-1</sup> respectively. This is much greater than the standard deviation at a distance greater than ±5 m from the spreading vehicle, 0.94, 1.58 and 2.16 kg ha<sup>-1</sup> at 80, 100 and 150 kg ha<sup>-1</sup> respectively.

*Calculated Certifiable bout width* - Figure 2.3(a-c) shows the CV curves at each of the three application rates (80, 100, 150 kg ha<sup>-1</sup>). Figure 2.3(a-c) shows large differences in calculated CV arising from variation in

measured test patterns using different testing methods. Predominately, this variation occurs near the centre ( $\pm 5$  m) of the distribution pattern where changes in tray layout between methods had the largest effect. Outside  $\pm 5$  m, the variation in spread pattern was small (Figure 2.2).

Table 2.4 shows that there is large variation in the certifiable bout width between testing methods at three tested application rates. At  $80 \text{ kg ha}^{-1}$  certifiable bout width ranged from 7.8 m to 19.2 m, the CV curves at  $80 \text{ kg ha}^{-1}$  (Figure 2.3a) all climb steadily until 7 m then all flatten off until 14 m. The two testing methods that required a combination of trays (ASAE (4 m), and ISO(ii)), and the ASAE (0.5 m) method, where only 10 trays were used gave the widest bout widths. This was caused by less micro-variation being expressed in the spread pattern than the other testing methods.

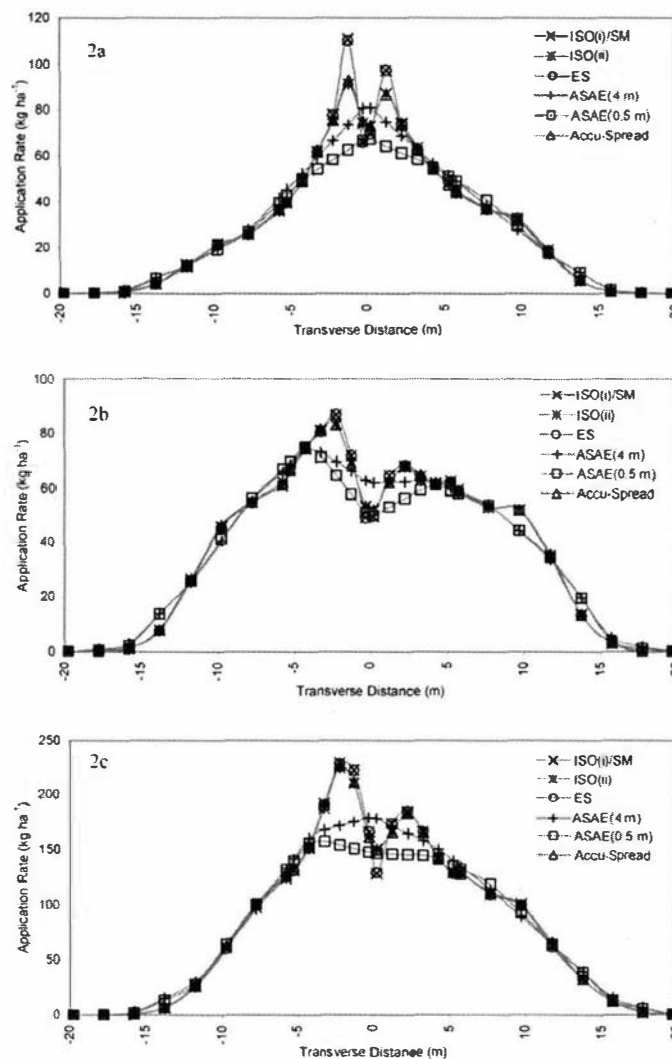


Figure 2.2. Average distribution graph at (a)  $80 \text{ kg ha}^{-1}$ , (b)  $100 \text{ kg ha}^{-1}$  and (c)  $150 \text{ kg ha}^{-1}$  when using six different international transverse test methods.

**Table 2.3. Variation in application rate at set intervals from the spreader from 36 combined transverse distribution tests at 80, 100 and 150 kg ha<sup>-1</sup>.**

App. Rate		Distance from spreader (m)							
		-20 to -15	-15 to -10	-10 to -5	-5 to 0	0 to 5	5 to 10	10 to 15	15 to 20
80 kg ha <sup>-1</sup>	Mean(kg ha <sup>-1</sup> )	0.45	10.21	29.14	66.66	65.28	37.34	11.64	0.34
	std dev(kg ha <sup>-1</sup> )	0.23	0.76	1.40	6.48	4.39	1.70	1.34	0.21
	Variance(kg ha <sup>-1</sup> )	0.07	0.72	2.56	69.14	32.63	3.10	1.98	0.06
100 kg ha <sup>-1</sup>	Mean(kg ha <sup>-1</sup> )	0.76	20.83	55.77	71.28	62.25	52.93	23.53	1.02
	std dev(kg ha <sup>-1</sup> )	0.47	2.30	1.95	4.68	2.97	1.87	2.28	0.61
	Variance(kg ha <sup>-1</sup> )	0.48	6.16	4.33	30.67	11.78	5.39	6.13	0.45
150 kg ha <sup>-1</sup>	Mean(kg ha <sup>-1</sup> )	0.68	23.22	101.30	180.39	156.73	111.20	47.24	5.05
	std dev(kg ha <sup>-1</sup> )	0.44	2.70	2.34	17.61	9.37	3.32	2.72	1.45
	Variance(kg ha <sup>-1</sup> )	0.49	8.28	6.62	458.53	110.93	12.10	8.20	2.43

**Table 2.4. Variation in certifiable bout widths using six different test methods and three target application rates where the transverse CV (%) was < 15%, application rate was not considered in this data set.**

Target App Rate	Method	Mean (m)	Std Dev (m)	Variance (m)
80 kg ha <sup>-1</sup>	ISO(i)/SM	7.8	2.2	4.7
	ISO(ii)	12.4	3.1	9.4
	ES	8.5	2.3	5.3
	ASAE(4 m)	17.7	0.7	0.4
	ASAE(0.5 m)	19.2	1.4	1.8
	Accu-Spread	11.8	3.3	11.2
100 kg ha <sup>-1</sup>	ISO(i)/SM	19.6	5.7	32.1
	ISO(ii)	11.9	1.8	3.4
	ES	14.1	4.2	18.1
	ASAE(4 m)	24.8	0.7	0.5
	ASAE(0.5 m)	19.8	5.8	33.8
	Accu-Spread	17.9	5.6	31.4
150 kg ha <sup>-1</sup>	ISO(i)/SM	17.5	3.4	11.6
	ISO(ii)	12.2	1.7	3.0
	ES	13.3	2.7	7.2
	ASAE(4 m)	21.3	2.1	4.5
	ASAE(0.5 m)	22.0	2.3	5.2
	Accu-Spread	16.6	3.6	12.6

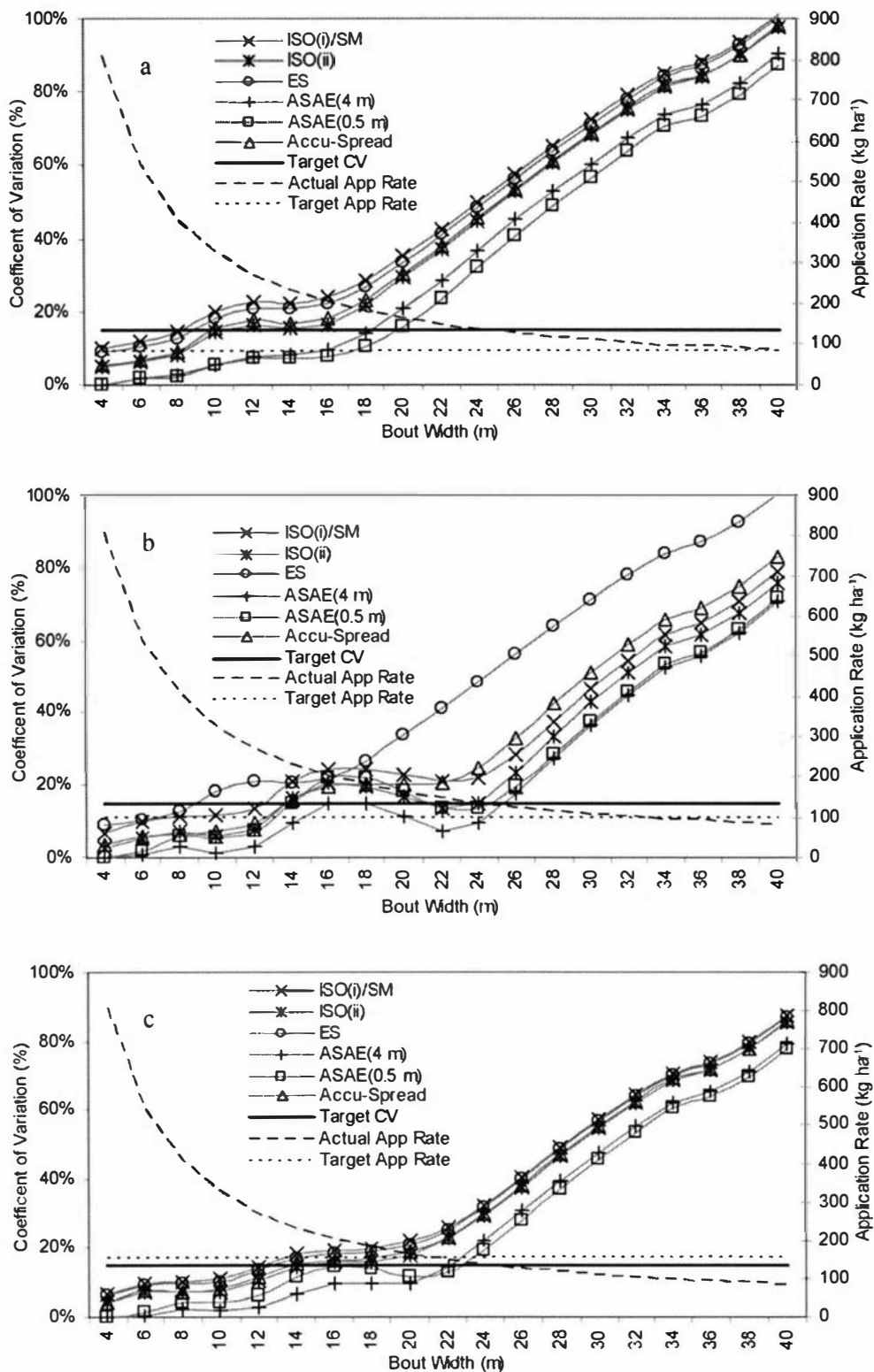


Figure 2.3. Coefficient of variation and average application rate at three target application rates - (a) 80 kg ha<sup>-1</sup>, (b) 100 kg ha<sup>-1</sup> and (c) 150 kg ha<sup>-1</sup>.

At  $100 \text{ kg ha}^{-1}$  where the distribution pattern followed a flattop distribution pattern the CV curve passed through the 15% CV limit twice using the ASAE (4 m) and ASAE (0.5 m) methods. The other methods, although following a similar shape, did not pass through the 15% CV limit twice, therefore, were certified at a lower bout width compared to those obtained at an application rate of  $100 \text{ kg ha}^{-1}$ . This meant that there was a large difference in certifiable bout widths (9 to 25 m) under the different testing methods. There was also large statistical variation within methods from the 36 repetitions where some tests passed under the 15% CV limit twice and some that only passed under the limit once. The ASAE (4 m) method was certified at the widest average width (24.8 m) with all tests coming under the 15% CV limit twice. Therefore, the standard deviation (0.7 m) and variance (0.5 m) was low with comparison to the other methods. In contrast to this, the ISO(ii) method only had an average certifiable bout width of 11.9 m. The CV curve never got below 15% CV after it initially went over this level, therefore, variation in certifiable bout width was also very low (Stdev = 1.8 m, Var = 3.4 m). The ISO(i)/Spreadmark method expressed a high level of variation in certifiable bout width (Stdev = 5.7 m Var = 32.1 m). This was due to the CV curve (Figure 2.3b) crossing the 15% threshold value twice on 15 of the 36 replications of the test, this was due to variation in individual transverse tests.

At an application rate of  $150 \text{ kg ha}^{-1}$ , variation was similar to that experienced at  $80 \text{ kg ha}^{-1}$ , largely due to the similar triangular shaped distribution pattern. The range in certifiable bout widths was less than that at  $100 \text{ kg ha}^{-1}$  (13 to 25 m), however variance was high in both the ISO(i)/Spreadmark and Accu-Spread methods because of the 15% threshold value being crossed twice.

*Confidence in certifiable bout width measurement* - The range in predicted bout width using all six international test methods was 18.4 m, 25.9 m and 18.7 m at 80, 100 and  $150 \text{ kg ha}^{-1}$  respectively (Figure 2.4). This large range was due to the high variability in simultaneous transverse tests at individual rates. There was a larger range in certifiable bout width at  $100 \text{ kg ha}^{-1}$  (15.9 m) than at 80 (8.6 m) and  $150 \text{ kg ha}^{-1}$  (10.6 m) over all test methods. The ASAE (4 m) method showed the least variation in bout width over the three application rates. However, this method used the average of eight trays in both the transverse and longitudinal direction (64 trays total), but this does not show the micro variation expressed in other methods. Variation in certifiable bout width was consistent for all three application rates when using the ISO(ii) method. Certifiable bout width was expected to fall between 6.2 & 18.5 m, 8.2 & 18.5 m and 8.7 & 15.7 m at 80, 100 and  $150 \text{ kg ha}^{-1}$

respectively. In contrast to this, the ISO(i)/Spreadmark method showed the greatest difference in expected certifiable bout widths across the three tested application rates, 3.5 to 12.1 m, 8.3 to 30.9 m and 10.7 to 24.3 m respectively. At application rates of 80 and 150 kg ha<sup>-1</sup> it was expected that the mean certifiable bout width for all testing methods would be within  $\pm 3.0$  m ( $P < 0.05$ ), however, at 100 kg ha<sup>-1</sup>, due to the higher degree of variability between spread patterns, the mean bout width for all methods could be expected to be within  $\pm 5.0$  m ( $P < 0.05$ ).

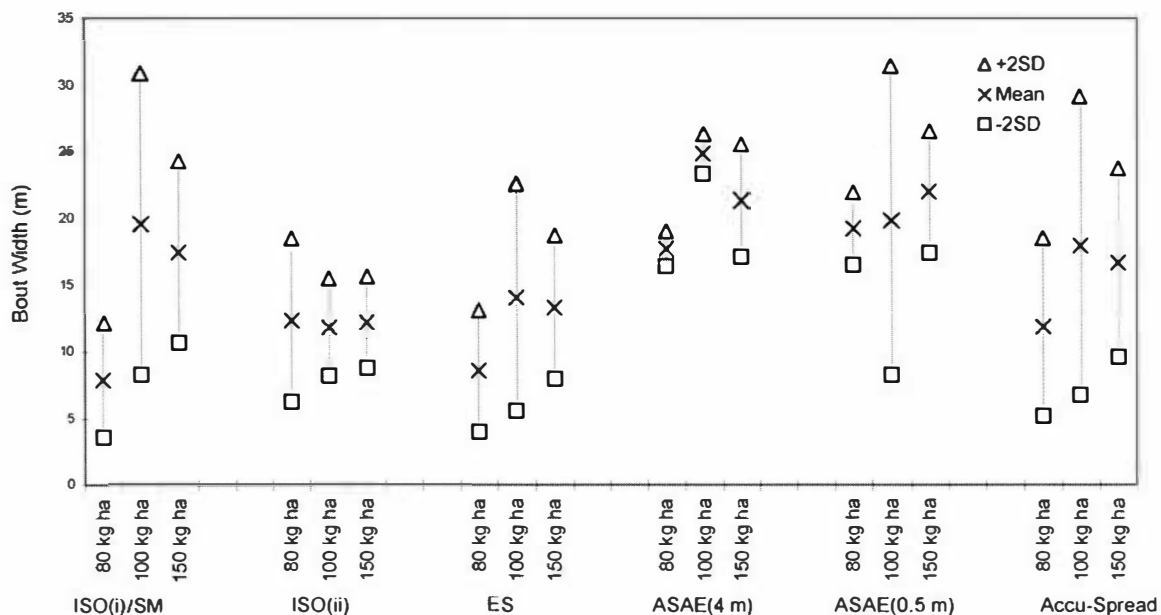
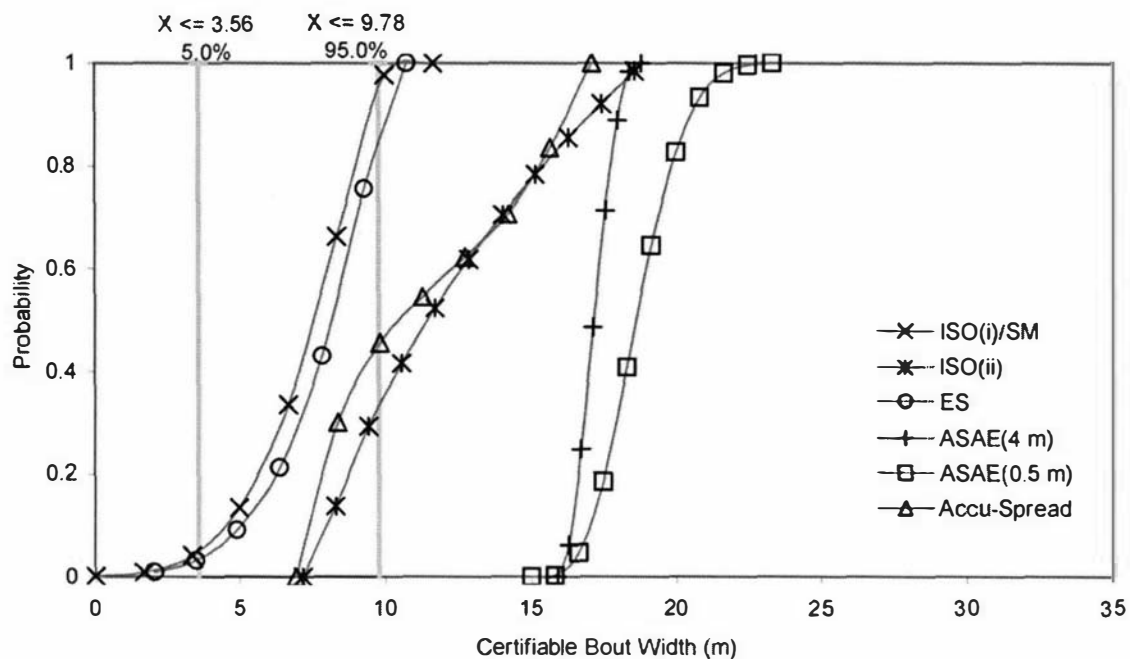


Figure 2.4. Range in calculated certifiable bout widths using six internationally recognised testing methods.

*Simulation Results* - An @Risk (Palisade, 2004) simulation was run for each test method at three application rates, 80, 100 and 150 kg ha<sup>-1</sup>. A beta distribution was used for the simulation; this was found to have the most consistent fit with the lowest reduced mean squared error (RMS). One thousand iterations were performed for each method at each rate. Certifiable bout width probability statistics were obtained from each simulation (Table 2.5). Each method was compared to the ISO(i)/Spreadmark method, as using this method covers the entire distribution with the most accuracy.

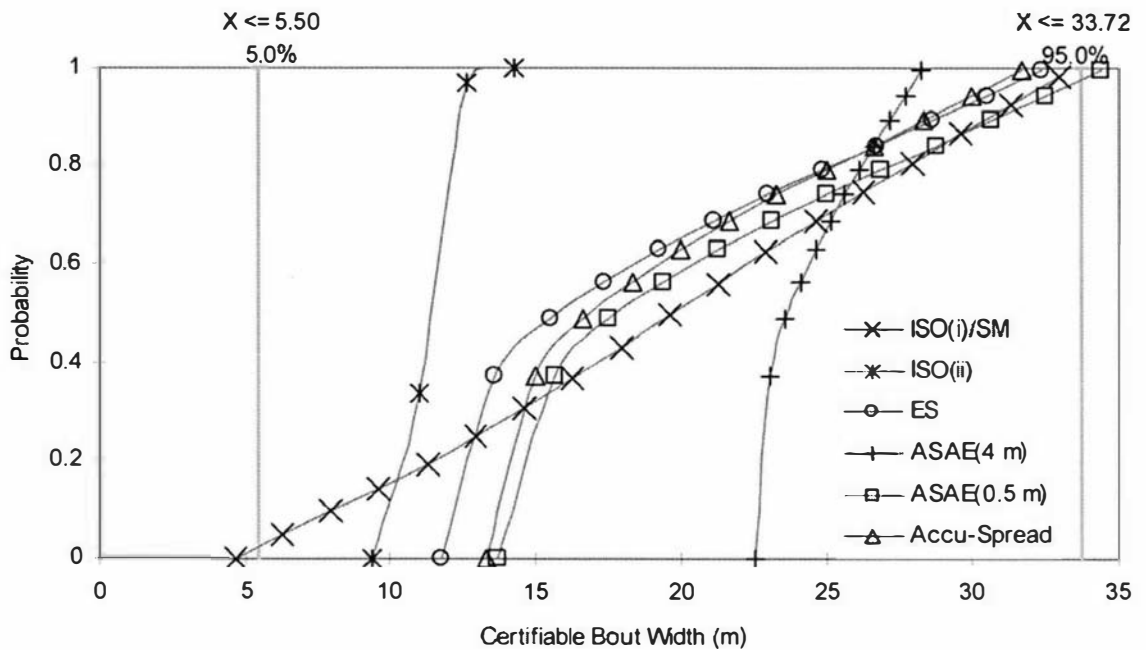


**Figure 2.5. Simulation of expected certifiable bout width from 36 transverse tests at 80 kg ha<sup>-1</sup> using six different testing methods.**

Simulation results showed that at 80 kg ha<sup>-1</sup> the actual certifiable bout width should fall between 3.56 and 9.78 m if the full distribution was to be measured. Figure 2.5 shows that the ES methods followed a similar distribution to that represented by the ISO/Spreadmark method. The ASAE (0.5 m) and ASAE (4 m) methods were found to simulate much higher certifiable bout widths (>16 m), whilst the ISO(i)/Spreadmark and ES methods simulation results were found to certify at much lower bout widths (<10.5 m). The Accu-Spread and ISO(ii) methods both simulated bout widths between 7.5 and 18.5 m. Figure 2.6 shows the range in probability distributions at 100 kg ha<sup>-1</sup> for the six test methods. It is shown that the ES, ASAE (0.5 m) and Accu-Spread methods all follow a similar distribution. However, these methods have very wide ranges in certifiable bout widths (12-34 m), but these distributions had similar variation as the ISO(i)/Spreadmark method. The high level of variation, and wider certifiable bout width than at other tested rates was caused by the flattop spread pattern; this produced an S-shaped CV curve. On 15 of the 36 replications at 100 kg ha<sup>-1</sup> the CV passed through the 15% CV limit twice meaning these repetitions were certified at much higher bout widths than others repetitions. The ISO(ii) method predicted bout widths within a very small range ( $\pm 2$  m), however, the range in bout widths was low (10.5-12.5 m) compared to those predicted using other methods. The ASAE (4 m) method simulation produced very high bout widths (23.0-25.5 m) and had a similar

distribution shape to that of the ISO (ii) method.

The simulated range in certifiable bout width at an application rate of  $150 \text{ kg ha}^{-1}$  is very similar regardless of method used (Figure 2.7). Variation in certifiable bout width over all methods was between 9.5 and 24.0m.



**Figure 2.6. Simulation of expected certifiable bout width from 36 transverse tests at  $100 \text{ kg ha}^{-1}$  using six different testing methods.**

The probability that each method would simulate the same result as that measured using the ISO(i)/Spreadmark method was calculated (Table 2.5). At  $80 \text{ kg ha}^{-1}$  there was a 0.83 probability that the ES method would calculate the same bout width as the ISO(i)/Spreadmark method. At  $100 \text{ kg ha}^{-1}$  all methods except the ASAE (0.5 m) method would calculate a bout width within the range of that simulated using the ISO(i)/Spreadmark method. This was due to the ISO(i)/Spreadmark method calculating either a high (24-25 m) or a low (12-13 m) bout width caused by an S-shaped CV curve (Figure 2.3b). At  $150 \text{ kg ha}^{-1}$  the Accu-Spread method calculated bout widths that were all within the range of that calculated by the ISO(i)/Spreadmark method ( $P < 0.001$ ). Examining all testing techniques, the ES and Accu-Spread methods best calculated bout widths within the range expressed using the ISO(i)/Spreadmark method with probabilities of 0.73 and 0.82 respectively.

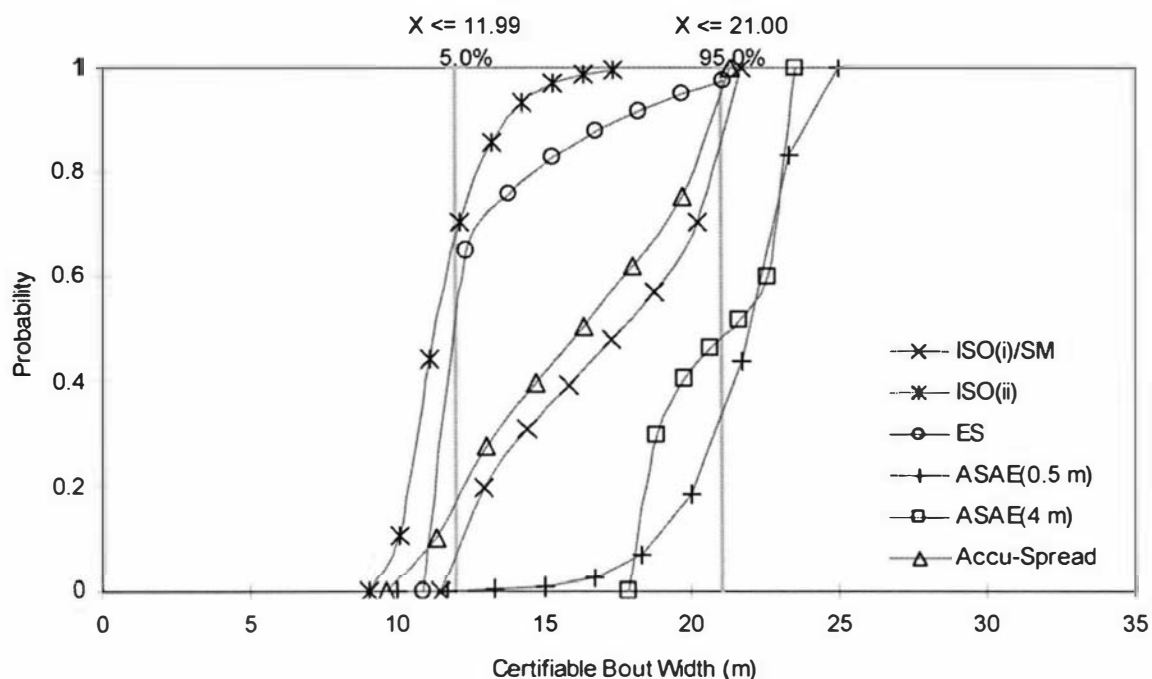


Figure 2.7. Simulation of expected certifiable bout width from 36 transverse tests at 150 kg ha<sup>-1</sup> using six different testing methods.

Table 2.5. Probability of a bout width being calculated from five international test methods that would be within the 90% confidence limit of that calculated from the ISO(i)/Spreadmark testing method at three application rates.

	ISO(ii)	ES	ASAE (4 m)	ASAE (0.5 m)	Accu-Spread
80 kg ha <sup>-1</sup>	0.33	0.83	0.00	0.00	0.45
100 kg ha <sup>-1</sup>	1.00	1.00	1.00	0.98	1.00
150 kg ha <sup>-1</sup>	0.33	0.36	0.48	0.32	1.00
Average	0.55	0.73	0.49	0.43	0.82

## 2.4. DISCUSSION

It is important when spreading fertiliser that a spreader can achieve a consistent level of performance at various application rates whilst driving at a specific bout width. It is shown from this study that this was not necessarily the case, with high levels of variation in certifiable bout width expressed from simultaneously collected test data.

The tested spreader had previously been certified to spread at a bout width of 17 m at 100 kg ha<sup>-1</sup> when spreading urea using the ISO(i)/Spreadmark testing method. The bout width was calculated from one transverse distribution test. Bout width calculation results, where transverse CV was < 15%, obtained from

multiple testing (36 tests at each application rate) varied significantly from this. Application rate variation was not considered as part of this testing, however, in order for tests to be ratified by the Spreadmark quality assurance program application rate must be within  $\pm 30\%$  of the target application rate.

Results showed that typical variation in spread pattern using all six international test methods was far greater around the centre of the distribution; outside  $\pm 5\text{m}$  at any application rate the variation between methods was minimal (Figure 2.2). This indicated that tray setup is much more important at the centre of the distribution pattern than at the outer limits. The method that best represented the variation expressed in all 36 single transverse tests was the ISO(ii) method. This method used larger trays (2.5 x 1 m) reducing the micro-variation expressed in other methods using regular sized trays (0.5 by 0.5 m).

The two ASAE methods gave the greatest difference from other methods at all three application rates (Figure 2.2); this was predominately due to the tray layout. The ASAE (0.5 m) method did not pick up the micro variation as there was only one 0.5 by 0.5 m tray per 4 m spacing, the ASAE (4 m) method used 4.0 by 4.0 m trays, therefore averaged out the micro variation in the spread pattern. This had the effect of increasing the certifiable bout width that the spreader could operate at.

There was no consistency between pattern shapes at the three application rates. The shape of the distribution pattern has a significant impact on the certifiable bout width. The use of different testing methods changes the distribution pattern, therefore there can be a significant influence on the calculated CV. At 80 and 150 kg ha<sup>-1</sup> the pattern was triangular, whilst at 100 kg ha<sup>-1</sup> the pattern was more representative of a flattop pattern. The typical CV pattern at all application rates was that of an S-shaped curve (Figure 2.3(a-c)). This pattern is commonly caused by a flattop spread pattern; this was selected as the best fit for the 100 kg ha<sup>-1</sup> distribution pattern (Figure 2.1). This theory is supported by Figure 2.3b where the S-shaped spread pattern is the most pronounced compared to that of Figure 2.3a and Figure 2.3c.

Fulton et al. (2001) demonstrated distribution variability at different application rates from a single spreader, indicating that this will possibly compound application errors. The variation in distribution pattern at the different application rates generated a wide range in bout widths, especially at 100 kg ha<sup>-1</sup> where 58% of transverse tests were certified at between 23 and 25 m with the remaining 42% being certified at only 13 m when using the ISO(i)/Spreadmark method. This compared with the ASAE (4 m) method where all 36 tests were certified between 24 and 26 m, whilst the ES method was the opposite, where 83% of 36 transverse tests

were certified at between 11 and 13 m.

Small variations in distribution patterns, especially in the centre of the distribution pattern (Figure 2.2), considerably changed the calculated CV. On average there was a  $\pm 10\%$  range in calculated CV at bout widths between 1 and 30 m when using the six different test methods. This range meant significant differences in the calculated certified bout width where transverse CV was less than 15%.

Simulation results showed that the ES and Accu-Spread methods gave similar results to that of the ISO(i)/Spreadmark method which measured the full distribution with the most precision. The ES and Accu-Spread methods have a similar tray layout to the ISO(i)/Spreadmark method, but, deal with longitudinal variation by averaging two transverse tests. The ES method uses continuous 0.5 x 0.5 m trays, whilst the Accu-Spread method uses the same size trays at a 1.0 m centre to centre spacing.

## **2.5. CONCLUSION**

There are differences between test methodologies, and direct comparison should therefore be avoided between methods. If comparison is required between two or more spreaders, then the same test method and tray layout should be used. The Spreadmark test method was adequate in predicting variation for single transverse tests, however, gave no measure as to the variability along the longitudinal axis. A multiple row test, such as the one used in this research, should be performed for new and modified spreaders to determine variability within single tests. Test methods that had a sufficient concentration of trays around the centre of the distribution pattern described the behaviour of the spreader with greater accuracy. Certifiable bout width was also influenced by the concentration of trays around the centre line, however, beyond  $\pm 5$  m of the centre line tray, concentration had little effect. Tray size was also an issue where larger trays were unsuccessful in picking up micro variation within the distribution pattern. Clearly, from results obtained from this spreader, it is practical to simplify testing procedures by reducing the number of trays beyond  $\pm 5$  m from the path of the spreader; however, this would only be applicable to spread patterns with flattop and triangular shape characteristics, not bimodal spread patterns. In further research, the impact of incorrect certification of spreader bout widths needs to be investigated on both a national and global scale in order to measure the agronomic and economic effects.

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## CHAPTER 3

# A STATISTICAL COMPARISON OF INTERNATIONAL SPREADER TEST METHODS TO TEST CONFIDENCE IN BOUT WIDTH CALCULATIONS

### *Paper Reference<sup>3</sup>*

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J.R. Jones., Lawrence, H. G., I. J. Yule. (2007). A statistical comparison of international spreader test methods to test confidence in bout width calculations. *Powder Technology XX: XXX–XXX. Received June 2007, Under Revision.*

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***Abstract.** Throughout the world a number of testing systems are used to obtain the spread pattern of fertiliser from spinning disc spreaders. The spread pattern is used to certify the bout width. These tests use trays aligned in one or two transverse rows to the direction of travel of the spreader which collect the fertiliser for one or more passes by the spreading vehicle. The tray size, their spacing in each row, the distance apart of the transverse rows and the number of passes all vary between tests. In this study, a field trial was constructed to simulate all international tests. The ground was covered with 0.5 × 0.5 m trays arranged as 18 transverse rows of 80 trays each, leaving spaces for the truck wheels. The amount of fertiliser landing on each tray was weighed for two replicates at each of three nominal application rates of 80, 100 and 150 kg ha<sup>-1</sup> of urea. These trials provide good sample statistics, which are used to estimate the confidence limits of the spread patterns for each international spread test and then to estimate the accuracy of correctly certifying the bout width. The ACCU Spread (Australia) method proved far superior in both aspects; it had the narrowest confidence limits for the spread pattern and the most accurate determination of bout width, which it could predict accurately to within one tray, or 0.5 m. The ES (Europe) method was next best, but is prone to a 'near neighbour effect' because the two adjacent rows of trays cannot be guaranteed to have longitudinal independence. Next were the ISO 5690/1, ISO 5690/2 and Spreadmark (New Zealand) tests, which all performed equally well. Interestingly, the ISO 5690/2 test uses a narrower tray (0.25×1.0 m) intended to obtain better transverse resolution, but this did not improve the accuracy of the bout width calculation. Last was the ASAE (USA) method, which lacks resolution because the trays are spaced at wide intervals across the swath. This work clearly demonstrates that multiple rows of trays and multiple passes of the spreader enhance the accuracy of the test.*

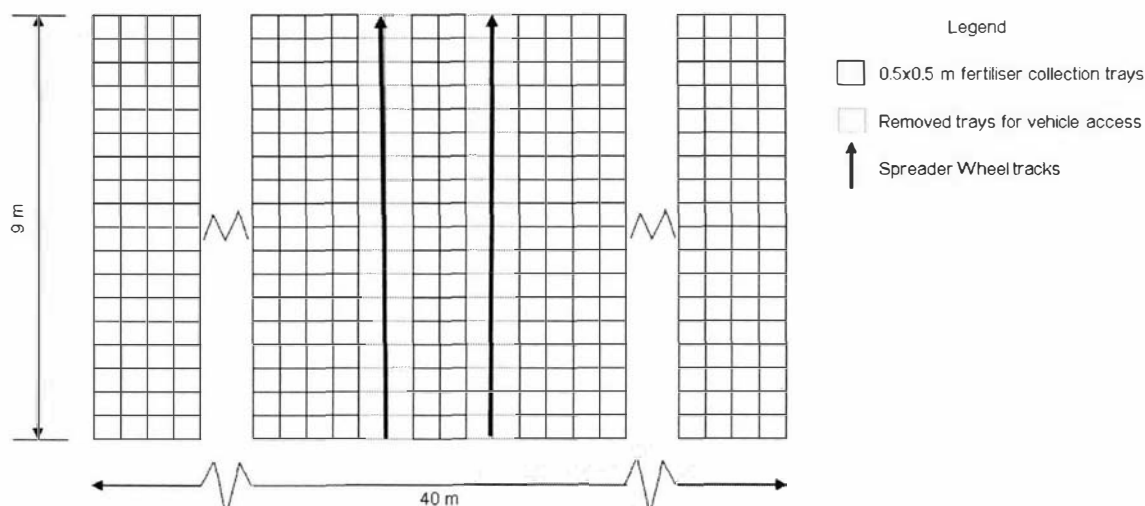
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<sup>3</sup> This chapter contains some changes to the published paper resulting from examiner emendations.

### 3.1. INTRODUCTION

There are several test methods used worldwide to certify fertiliser spreaders. Certification determines the allowable distance between adjacent transects of the spreader as it is driven across the field. Each international test method has a different test protocol, but all measure the amount of fertiliser landing on trays. They are; (i), the ISO standard (ISO, 1985); (ii), ASAE standard (ASAE, 1999); (iii), European Standard (CEN, 1999) operated in European Union countries; (iv), ACCU-Spread (AFSA, 2001) in Australia; and (v), Spreadmark (NZFQC, 2006) in New Zealand. These test methods are simple to set up and conduct, requiring only collection trays and weigh scales.

Alternative technologies can be used to predict spread pattern but none of these methods are used to test spreader performance. These methods include using image processing (Hensel, 2003), mathematical calculation, cylinder measurement and the use of optical sensors and ballistic modelling have also been successfully used to predict spread pattern information, but are not covered in the present analysis. A new test device for centrifugal spreaders is described by Piron & Miclet (2006). The method moves a spreader radially around a single row of collection trays fitted with load cells in order to define the spatial distribution of the spreader. The method can be used to extract a smoothed transverse spread pattern rather than an instantaneous spread pattern as acquired from the international test methods discussed.



**Figure 3.1. Test tray layout used to reconstruct international fertiliser spreader test methods. 1400 0.5 x 0.5 m collection trays were used to construct a 80 x 18 (40 x 9 m) tray matrix (See also Fig. 2.1 (chapter 2) and Fig. 3.8).**

Each of the standard spread tests have trays arranged in transverse rows, some having more than one row, over which the spreader makes a given number of passes. The mass of fertiliser landing in the trays is either measured after each pass or after the passes have been completed depending on the test method. A test is made for each designated application rate of each fertiliser tested. Table 3.1 provides the details of individual test methods.

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The fertiliser mass collected in trays from spreader testing provides a measure of the uniformity of the transverse distribution from which the *bout width* is calculated. The *bout width* is the allowable distance between adjacent transects of the truck spreader as it is driven across the field. This paper directly compares the accuracy of these international spreader tests using a comprehensive field trial from which all tests can be reconstructed. The field trial consisted of  $0.5 \times 0.5$  m trays arranged as 18 adjacent transverse rows of 80 trays each, leaving spaces for the truck wheels (Figure 3.1). Two passes were made at each application rate and the mass of fertiliser (in grams) landing in each tray every pass was measured.

**Table 3.1. Test constraints for various international testing programs used around the world to test the transverse distribution accuracy of fertiliser spreaders.**

Standard	Tray Size	Tray Frequency	Transverse Spacing	No. of Rows	No. of Passes	Weigh frequency*
(i)ISO Standard 5690/1 (World)	0.5 × 0.5 m	Enough to cover total distributing width	Continuous	1	Test requires 3 fertilisers (typically lime, superphosphate, urca), 1 pass for each	Each pass
(ii) ISO Standard 5690/2 (World)	0.25 × 1.0 m	Enough to cover total distribution width	Continuous	1	Test requires 3 fertilisers (typically lime, superphosphate, urca), 1 pass for each	Each pass
ASAE S341.3 (USA)	0.5 × 0.5 m	10 per swath	Uniform spacing	1	1	Each pass
ES (Europe)	0.5 × 0.5 m	112 per 56 m	Continuous (centred 0.5 m apart)	2 adjacent	Test requires 6 fertilisers, 1 pass each	Each pass
ACCU-Spread (Aus)	0.5 × 0.5 m	25 per 25 m	Continuous	2, 50m apart	Test requires a minimum collection of 600 kg ha <sup>-1</sup> (c.g. 6 passes at 100 kg ha <sup>-1</sup> , 4 passes at 150 kg ha <sup>-1</sup> )	After minimum collection
Spreadmark (NZ)	0.5 × 0.5m	60 per 30 m	Continuous (centred 0.5 m apart)	1	Test requires 3 fertilisers, 1 pass each	Each pass

\* Weigh frequency defines whether the mass collected is weighed after each pass or after all passes.

<sup>#</sup> Typical application rates are 80-150 kg ha<sup>-1</sup> for urea, 200-500 kg ha<sup>-1</sup> for super and 500-1000 kg ha<sup>-1</sup> for lime.

### 3.2. METHODOLOGY

In order to accommodate all international tests, a matrix of 1400 collection trays covering the entire distribution width of the spreading vehicle were laid out edge to edge consisting of 18 transverse rows (Figure 2.1). Each row contained 80 trays with four lines of trays removed for the wheels of the spreader truck. To calculate the spread pattern in all test methods, trays that are absent are credited with the weighted average of trays at either side of them. The collection trays comply with the Spreadmark Standards, each measuring 0.5m wide, 0.5 m long and 0.15 m high and made of 4 mm thick plastic. A series of cardboard dividers (0.1 m high) were placed inside each tray to reduce particle energy on impact and avoid particles from ricocheting out.

Urea (46% N) was chosen as the test fertiliser, which is commonly applied at rates between 80 kg ha<sup>-1</sup> and 150 kg ha<sup>-1</sup> in New Zealand. Therefore fixed application rate tests were conducted at a low (80 kg ha<sup>-1</sup>), medium (100 kg ha<sup>-1</sup>), and high (150 kg ha<sup>-1</sup>) rates. Two replicates were made of each application rate meaning that 36 transverse rows of data was obtained.

The spreader used was a Transpread 'W' chain twin spinner on a Mercedes truck. The spreader has an electronic flow control system to control the application rate as a function of driving speed by altering the hopper belt speed. The machine settings were the same as used for field spreading of urea, where the spreader had previously been certified under the Spreadmark, NZ quality assurance program (NZFQC, 2006) to spread to a bout width of 17 m at an application rate of 100 kg ha<sup>-1</sup> of urea. A spinner disc speed of 750 RPM was used for all tests. The hopper had a capacity of 10 tonnes. For these tests, 200 kg of urea was placed at the rear of the spreader to cover the feed mechanism which was found to be sufficient to produce normal flow. Tests were conducted on a flat asphalt surface. Wind speed was monitored during all experiments to ensure that the specified maximum wind speed was not exceeded (<2 m s<sup>-1</sup> to conform to all test methods).

The spread material was collected from each tray into individual labelled bags and later weighed using scales accurate to ±0.01 g. Particle size distributions were not investigated in this study. However, one observation of statistical importance is that larger particles were thrown further from the point of distribution. This means that the mass collected near the outer edge of the swath consisted of a small number of large particles. Because mass is a discrete function of the number of particles, when the numbers are fewer the variability is inherently higher.

#### *Statistical analyses applied to international test methods*

The total mass collected by the trays is

$$M_{trays} = \sum_{k=1}^p \sum_{j=1}^r \sum_{i=1}^n x_{k,j,i} \quad (1)$$

where  $n$  is the number of trays in a transverse row,  $r$  is the number of rows and  $p$  is the number of passes employed in the test. However, the total mass distributed by the spreader also includes fertiliser landing on the ground left bare for the truck wheels. By convention, the amount landing on these absent trays is interpolated

weighted average from the neighbouring trays. The following calculations are performed for each longitudinal position.

The mean amount of material landing at the  $i^{\text{th}}$  transverse tray position,  $\bar{x}_i$  is

$$\bar{x}_i = \frac{\sum_{k=1}^p \sum_{j=1}^r x_{k,j,i}}{pr}. \quad (2)$$

The sample standard deviation at  $i^{\text{th}}$  transverse tray position,  $S_i$ , is calculated from the sample variance

$$S_i^2 = \frac{\sum_{k=1}^p \sum_{j=1}^r (x_{k,j,i} - \bar{x}_i)^2}{pr - 1}. \quad (3)$$

The uniformity of the spread is measured by the coefficient of variation,  $CV_i$ , where the subscript  $i$  refers to the  $i^{\text{th}}$  transverse tray position

$$CV_{i, \text{tray}} = \frac{S_i}{\bar{x}_i}. \quad (4)$$

However, the international spread tests collect and weigh the fertiliser only once from each row which means they cannot calculate an expected mean or variance at each longitudinal position. Therefore they use a swath averaged measure of variation given by

$$MV_i = \frac{x_i}{\bar{x}} \quad (5)$$

where  $x_i$  is the amount of fertiliser landing on the  $i^{\text{th}}$  tray and  $\bar{x}$  is the mean averaged over all trays in the test,

$$\bar{x} = \frac{M_{\text{trays}}}{prn}. \quad (6)$$

Certification is an outcome of these international spread tests. In practice this means the  $MV_i$  calculations are repeated a number of times by overlapping the test results at various bout widths until an optimum is achieved. Clearly, overlapping will affect  $M_{\text{trays}}$ ,  $x_i$ ,  $\bar{x}_i$  and  $S_i^2$ , particularly for the outer regions of the swath. The optimum is defined as the maximum bout width across which  $MV_i \leq 0.15$  (In this case where nitrogen based fertiliser was used). This study will firstly compare the international tests based on their test variability. This will establish the confidence with which the certifiable bout width can be calculated.

The application rate,  $A_i$  ( $\text{kg ha}^{-1}$ ), at each  $i^{\text{th}}$  transverse position is converted from the mass of fertiliser measured in all  $r$  rows for all  $p$  passes and the summed area of each tray (7). For a single tray, without overlapping, the application rate is simply forty times the amount landing on the tray,

$$A_i = \frac{40}{pr} \sum_{k=1}^p \sum_{j=1}^r x_j \left[ \frac{\text{kg}}{\text{ha}} \right] \quad (7)$$

In these calculations of the statistics of spreading at each  $i^{\text{th}}$  transverse tray position, it must be noted that we assume independence between the rows. Independence means that the mass landing on one tray is independent of the mass landing on the same tray in an adjacent row. In contrast, we do not expect independence in the transverse direction because some sort of spread pattern is expected.

A number of things can affect variability such as ground topography<sup>4</sup> or time dependent behaviours within the spreading machine. This potential problem of lack of longitudinal independence affects tests that have adjacent or closely spaced rows of trays, namely the study reported here and the ES international spread test which has two adjacent rows of trays. The data set presented here will be used to ascertain whether a “near neighbour effect” exists and, if so, to determine the row spacing necessary to ensure independence.

Statistically we can detect this near neighbour effect by calculating the difference between masses landing on adjacent trays at the same ( $i^{\text{th}}$ ) transverse tray position

$$d_i = x_i - x_{i+1}. \quad (8)$$

The variance of the differences at each  $i^{\text{th}}$  tray position is then

$$S_{d,i}^2 = \frac{\sum_{i=1}^{n-1} d_i^2}{n-2} \quad (9)$$

where  $d_i$  is the adjacent tray difference and  $S_{d,i}^2$  is the sample variance of the differences. If the mass landing on the trays is independent, that is no periodicity occurs over the 18 rows of trays, then the difference variance should be approximately twice the measured variance<sup>5</sup>,  $S_{d,i}^2 \approx 2S_i^2$ , for the 17 differences that are obtained from an 18 tray test. The statistical *f-test* uses a one tailed test to determine the probability that the variances of the two populations are the same assuming that they are both normally distributed. As a spreadsheet operation, the 18 rows of masses collected were multiplied by  $\sqrt{2}$  and compared in the FTEST Microsoft Excel worksheet function to the 17 pairs of difference values. (The multiplier  $\sqrt{2}$  is needed to obtain twice the original sample variance.) The *f-test* assumes the two arrays of values are normally distributed so it is important to test this assumption. Although not shown here, the masses are distributed normally about the means over most of the spread swath, but the assumption breaks down at the outer edges where little fertiliser lands and the variability is high.

### 3.3. RESULTS

Comprehensive field test results were obtained for each nominal application rate (80, 100 and 150 kg ha<sup>-1</sup>) using the method described previously. Results were tested using the Shapiro-Wilk W test for normality.

<sup>4</sup> Furrows (or remnants of) are a typical ground topography affecting variability.

<sup>5</sup> This relationship is often quoted in the literature, however, to the authors knowledge noone references a source. Therefore, this result is derived in appendix A.

The dataset was found to be normally distributed about the mean, therefore, the calculated mean and variance can be given by equations (2) and (3) where  $r = 18$  and  $p = 2$ . The uniformity is measured by the coefficient of variation (4) and the industry measure of variation (5). Figure 3.2 plots the mean and 95% confidence interval (2 standard deviations) as a function of tray position for all three nominal application rates. Figure 3.3 plots the coefficient of variation for each tray  $CV_i$  and the industry measure of variation  $MV_i$ . Clearly the uniformity of the distribution becomes worse near the edges of the distribution pattern where  $CV_i$  goes from  $\sim 0.3$  to 6.0 between 12 and 18 m from the centreline of the spreading vehicle. Similarly the  $MV_i$  approaches zero. These results do not represent an ideal spread pattern where the mean and its variability are constant across the mid section of the swath. Further comment about this aspect of these results and their implication to fertiliser spreading is discussed in chapter 2. Instead, this paper aims to compare the international test methods using these results. First, the issue of independence between the amount of fertiliser landing on adjacent rows of trays is addressed, after which the expected variability of international tests and the confidence in the bout width calculations are determined.

### *Near Neighbour Effect*

It is possible that the masses of fertiliser collected on adjacent trays at a given longitude are not independent. Figure 3.4 shows the mass collected at selected transverse tray positions over the 18 rows of the test. It is clear that some interdependency occurs between trays, however, not all longitudinal positions shows these patterns. Because the number of rows is small, interrogation by Fourier analysis only reveals what the eyes see; that is some periodicity occurs over a 2 to 8 tray cycle. It must be noted that because of the small sample size, both Fourier analysis and visual inspection are susceptible to recognising experimental artefacts of periodicity. In this work, the dependency between trays is termed a *near neighbour effect*, where the variance of the difference between adjacent trays ( $S_d^2$ ) is significantly more than twice the variance expected for all 18 rows ( $2S_i^2$ ). Figure 3.5 compares these variances for both passes at each application rate. At 80 and 100 kg ha<sup>-1</sup> they appear similar. This is confirmed by the statistical *f-test*, shown in Figure 3.6, which shows the probability that the two variances,  $2S_i^2$  and  $S_{d,i}^2$ , are the same at each longitudinal tray position; the majority of the comparisons have probabilities  $> 0.7$  that the variances are the same<sup>6</sup>. Therefore, for later calculations it is assumed that the near neighbour effect is not present for the 80 and 100 kg ha<sup>-1</sup> application rates. This is not surprising as the flat tarmac over which the test was conducted removes ground topography as an influencing factor and also removes some machine parameters associated with vehicle roll. In contrast, the 150 kg ha<sup>-1</sup> application rate shows a time dependent behaviour which can be seen in Figure 3.4 where the fertiliser mass per tray increases with row number. The cause of this is not known; pass two did not have this increasing trend although all machine and environmental factors were the same. Also, within the longitudinal profile other periodicities can be seen by visual inspection and Fourier analysis. The result is that the *f-test* plot (Figure 3.6c) is a scatter diagram with probabilities evenly distributed between 0 and 1.

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<sup>6</sup> The selection of the significance level is arbitrary. Although each *f-test* compares the variance of 18 rows of data to 17 pairs, hence constituting a small sample, there are many transverse tray positions for which this comparison is made.

The presence of a near neighbour effect demonstrates that rows of trays should not be adjacent in order to obtain an accurate measure of the variance. Wider tray spacings can also be tested for the near neighbour effect, for example, by calculating the variance of the differences between every 3<sup>rd</sup>, 4<sup>th</sup>, 5<sup>th</sup>... $n^{\text{th}}$  tray. Figure 3.7 shows the *f-test* result for every 8<sup>th</sup> tray for the 150 kg ha<sup>-1</sup> application rate. The probabilities that the variances  $S_j^2$  and  $2S_i^2$  are similar are generally higher compared to Figure 3.6c, but are not as good as the 80 or 100 kg ha<sup>-1</sup> application rates due to the net increase in fertiliser across the rows on the negative (tray position) side of pass 1 and an observed dip in the middle rows of the positive side of pass 2 (not shown). Because differences are calculated when determining the near neighbour effect, this technique cannot account for time average trends in the mean. Therefore, for later calculations at the nominal application rate of 150 kg ha<sup>-1</sup>, the sample mean and variance will be used although it is acknowledged that time averaged trends did occur in the test data.

The only way to detect the near neighbour effect is in a large field trial such as conducted here. However, this is not commercially practical. A small test like the ES international spread test which does use adjacent rows will not pick up a near neighbour effect if it exists. To avoid this possible problem, the rows in an international test method should be spaced as far apart as feasible to ensure independence.

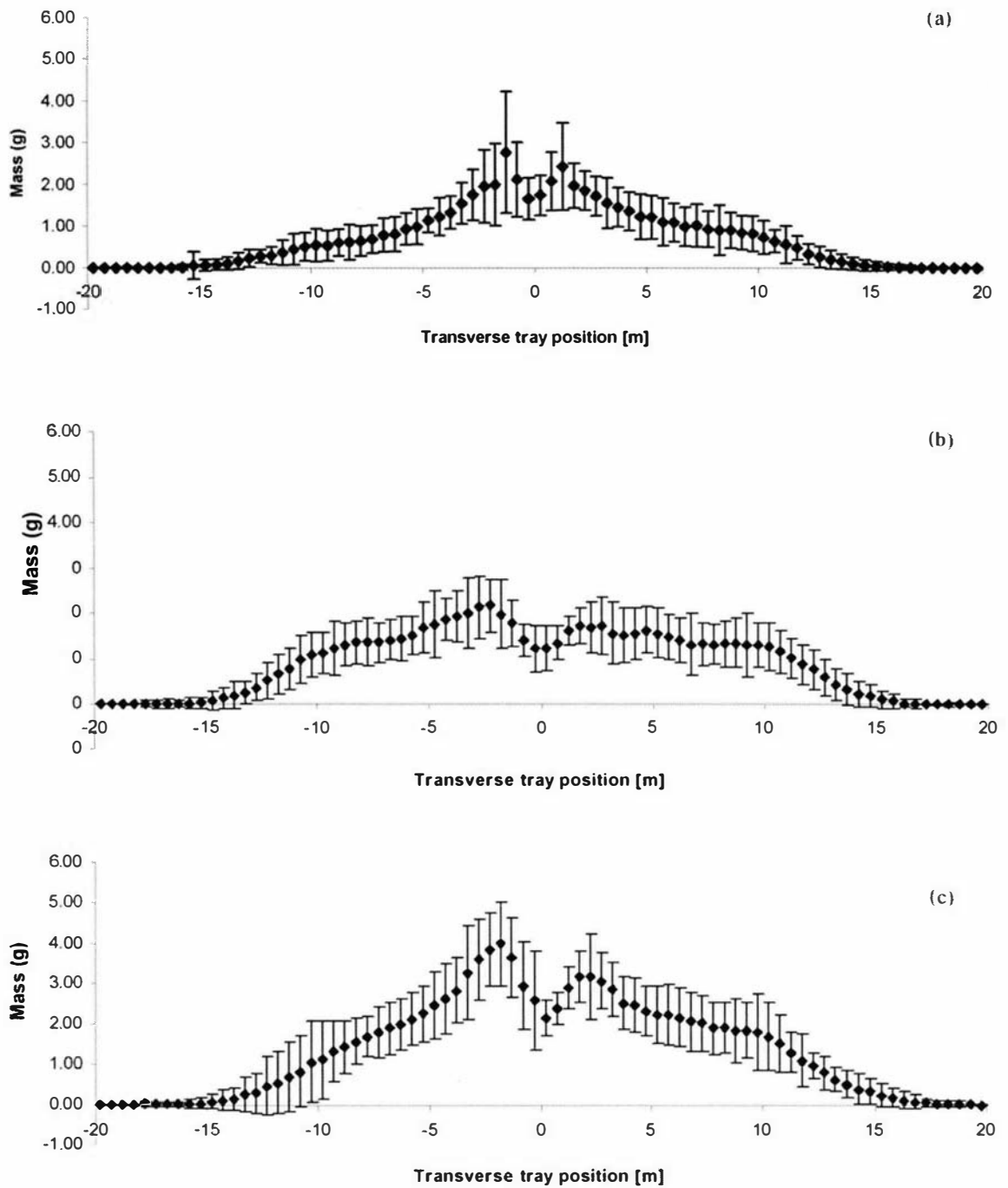


Figure 3.2. Mean and 95% CI (2 s.d.) for urea granule mass landing on trays as a function of longitudinal position, at nominal application rates of (a) 80 kg ha<sup>-1</sup>, (b) 100 kg ha<sup>-1</sup>, and (c) 150 kg ha<sup>-1</sup>.

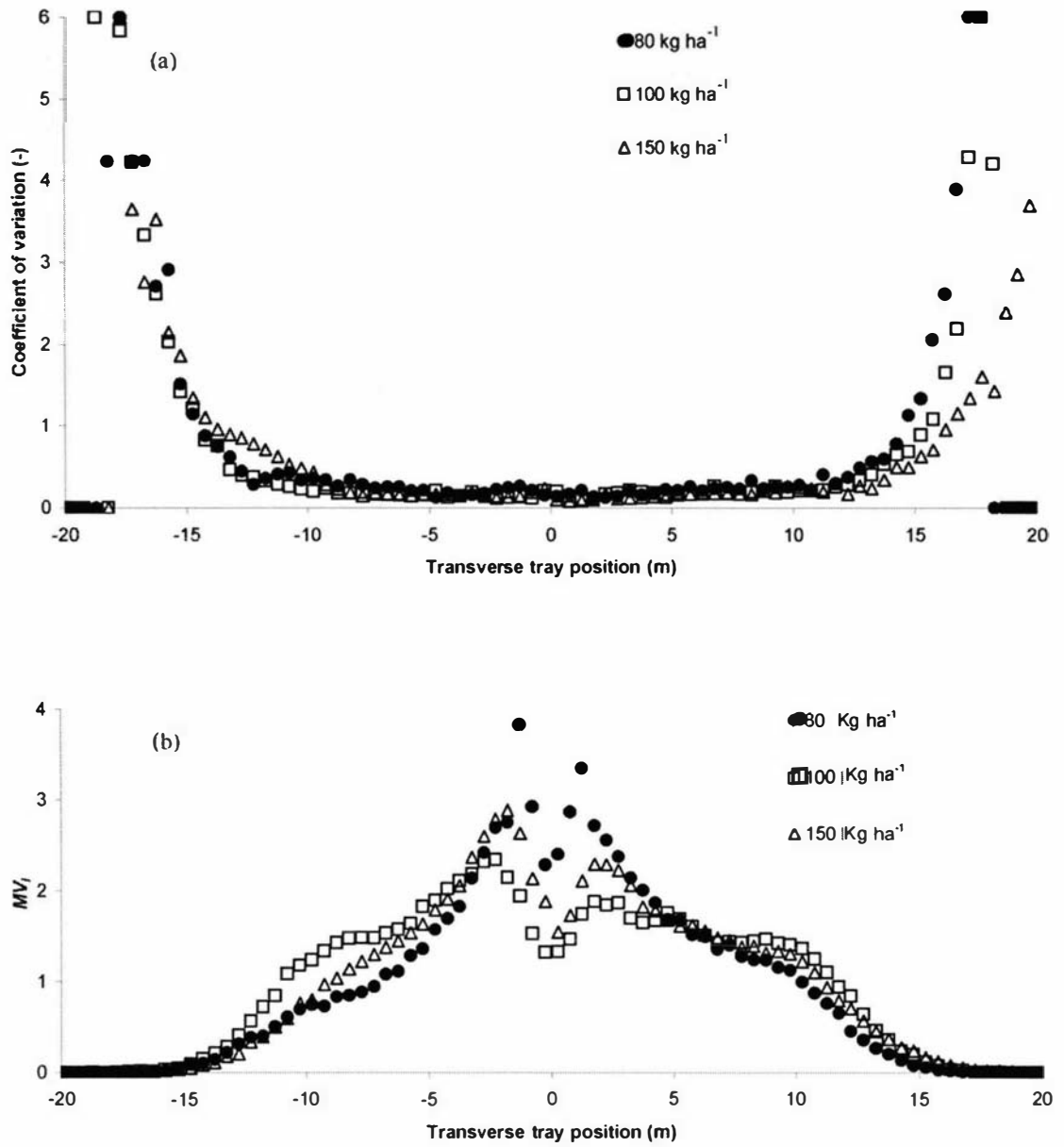


Figure 3.3. (a) Coefficient of variation  $CV_i$ ; and (b) expected industry measure of variation  $MV_i$ , plotted as a function of transverse tray position at nominal application rates of 80 kg ha<sup>-1</sup>, 100 kg ha<sup>-1</sup>, and 150 kg ha<sup>-1</sup>.

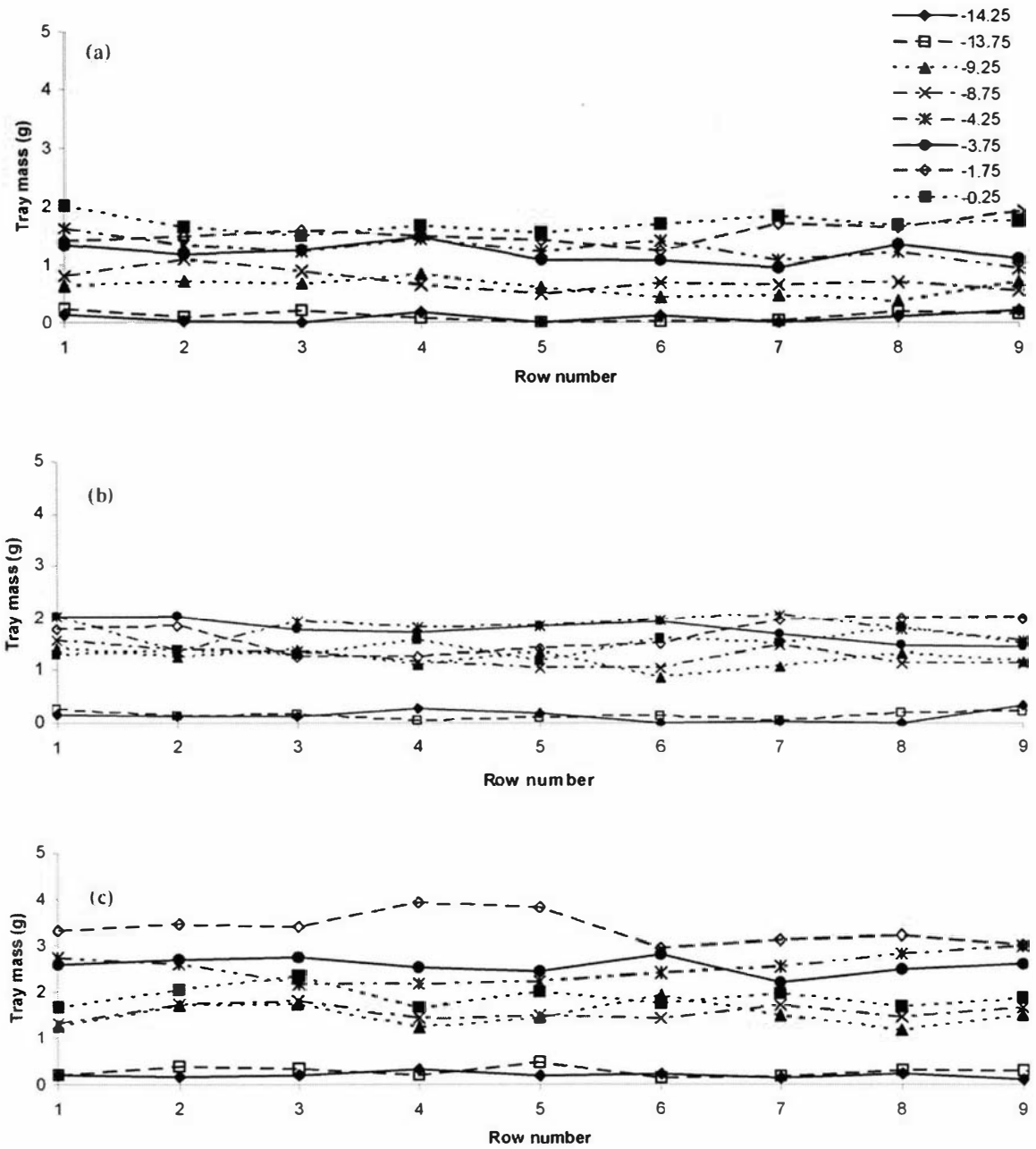


Figure 3.4. Urea granule mass collected on trays at selected transverse tray positions over all 18 rows at nominal application rates of (a) 80 kg ha<sup>-1</sup>, (b) 100 kg ha<sup>-1</sup>, and (c) 150 kg ha<sup>-1</sup>.

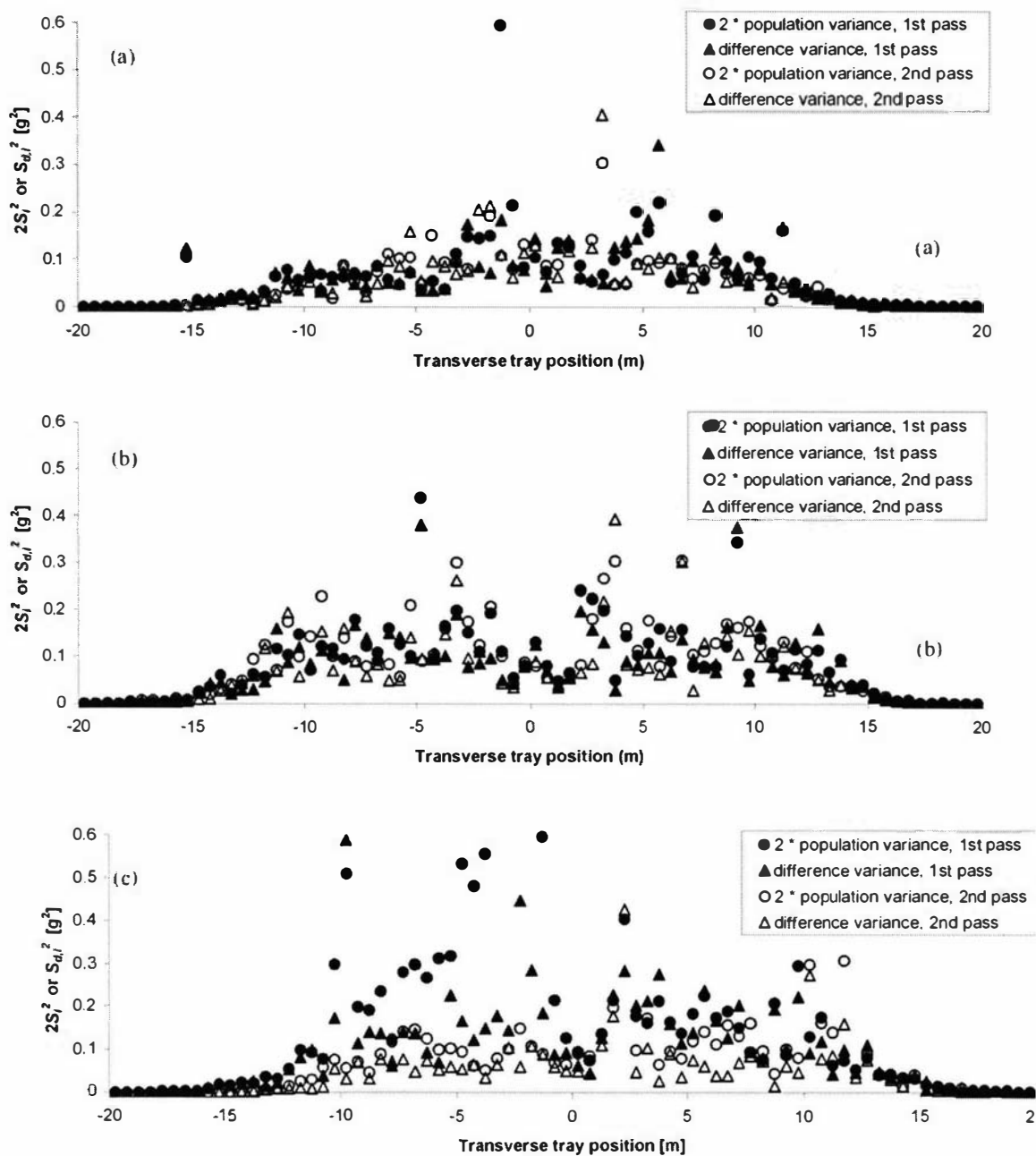


Figure 3.5. Comparison between  $2S_i^2$  and  $S_{d,i}^2$ , where  $2S_i^2$  is twice the variance of the masses collected and  $S_{d,i}^2$  is the variance of differences between masses landing on adjacent trays. Results are shown for the both passes at each nominal application rate (a) 80 kg ha<sup>-1</sup>, (b) 100 kg ha<sup>-1</sup>, and (c) 150 kg ha<sup>-1</sup>.

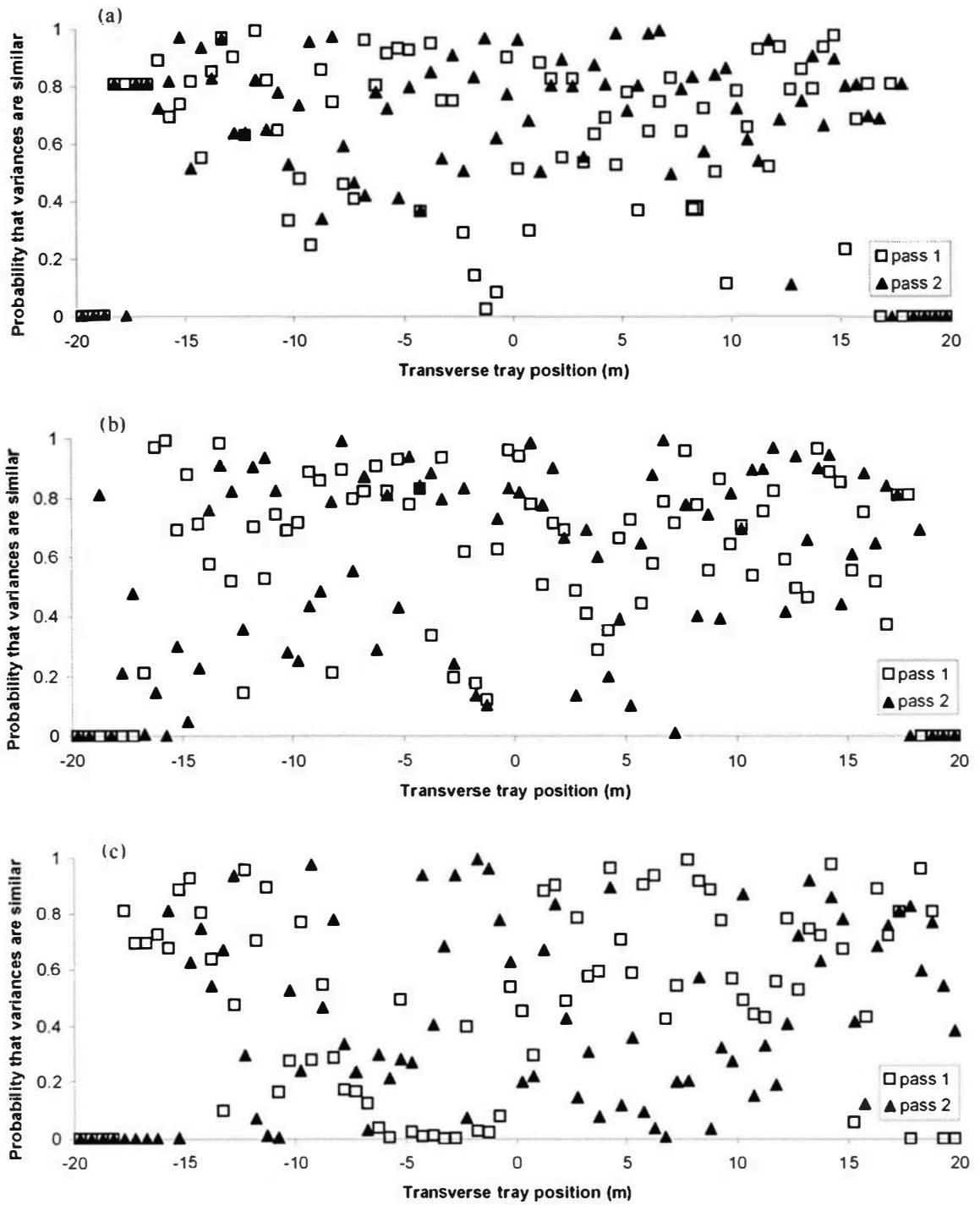


Figure 3.6. F-test comparison between pass pairs of  $2S_i^2$  and  $S_{d,i}^2$  as a function of tray position, where  $2S_i^2$  is twice the variance of the masses collected and  $S_{d,i}^2$  is the variance of differences between masses landing on adjacent trays. Results are shown for the both passes at each nominal application rate (a) 80 kg ha<sup>-1</sup>, (b) 100 kg ha<sup>-1</sup>, and (c) 150 kg ha<sup>-1</sup>.

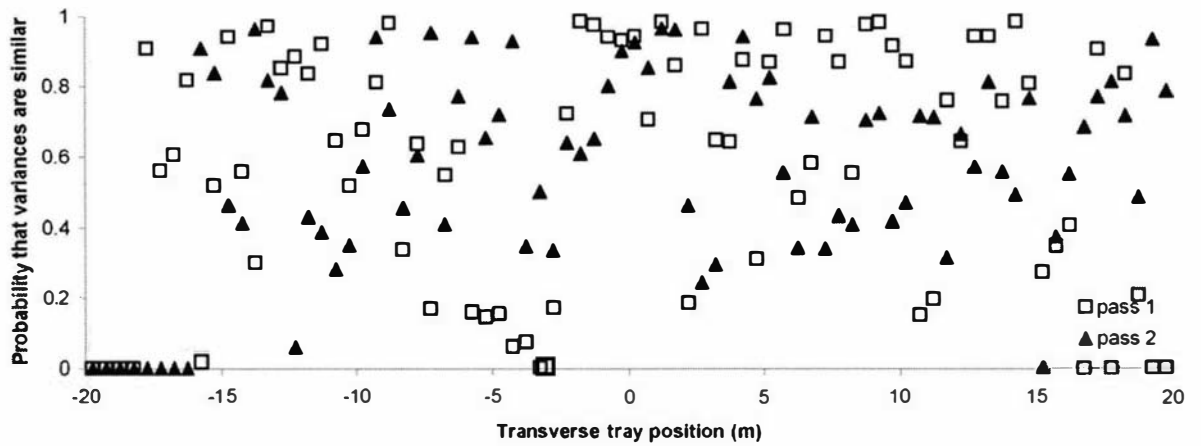


Figure 3.7. F-test comparison of variances  $S_i^2$  and  $S_{d,i}^2$  as a function of tray position, where  $S_i^2$  is twice the variance of the masses collected and  $S_{d,i}^2$  is the variance of differences between masses landing on every 8th tray.

Results are shown for the both passes at a nominal application rate of 150 kg ha<sup>-1</sup>.

**International Test Reconstruction**

The tray layout for each international spread test is shown in Figure 3.8. The statistical confidence of each international test can be reconstructed from the sample mean and variance obtained in the large field trial (2 passes of 18 × 80 trays) given in Figure 3.2.

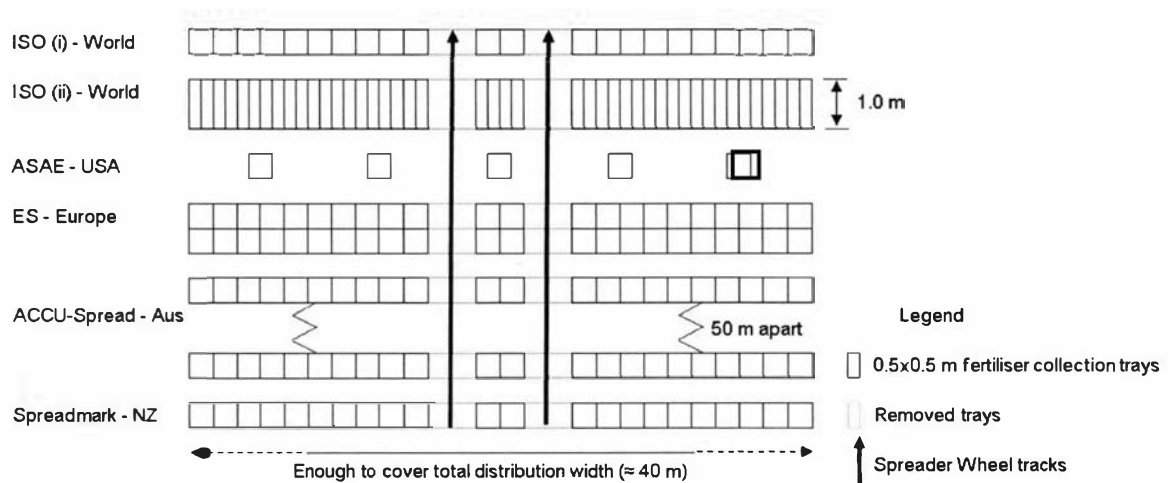


Figure 3.8. Test tray layouts for six international test methods reconstructed from a 1400 tray matrix (Figure 3.1) to compare levels of confidence in individual tray mass measurement.

The ISO (i) (World), ES (Europe), ASAE (USA), and Spreadmark (NZ) spread tests have the same expected mean and standard deviation,  $\bar{x}_i$  and  $\sigma_i$ , as obtained for the longitudinal positions in the large field trial. While the ASAE has the same expected values, these are for the minimum 10 trays across the swath. Because the certified *bout width* of the spreader used is nominally 15 m, the trays are positioned at intervals of 3 m for this analysis. Normally one tray is placed at the centreline of truck travel, but here it is offset slightly to align with the tray positions in the large field trial.

For tests that have larger tray sizes, multiple passes and multiple rows, the row mean and standard deviation are given respectively by

$$\bar{x}_{test,i} = \frac{pR}{r} \sum_{l=1}^c \bar{x}_{i,l} \quad [10]$$

$$\sigma_{test,i} = \sqrt{\frac{pR \sum_{l=1}^c \sigma_{i,l}^2}{r}} \quad [11]$$

where  $R$  and  $c$  define the row and column size of the larger test trays compared to the 0.5×0.5 m trays used in the large field trial, in all test  $R = 1$  and  $c = 1$  except for the ISO (ii) (World) test discussed below.  $p$  is the number of passes before the mass of fertiliser is measured,  $r$  is the number of transverse rows each test employs. The test statistics  $\bar{x}_{test,i}$  and  $\sigma_{test,i}$  are the longitudinal mean and standard deviation of fertiliser mass at the nominated  $i^{th}$  transverse position.

The ISO (ii) (World) uses a tray size of 0.25×1.0 m, aligned edge-to-edge in a single transverse row with a single pass. Because the tray area is the same as the 0.5×0.5 m trays, the mean and standard deviation for each tray are taken as the same as those for the corresponding half metre tray in our large field trial. The ACCU-Spread (Aus) test uses two transverse rows of trays of 0.5×0.5 m size, but only measures the mass of fertiliser after a minimum of 600 kg ha<sup>-1</sup> has been applied. For an application rate of 80 kg ha<sup>-1</sup> this means 8 passes, with 6 passes at 100 kg ha<sup>-1</sup> and 4 passes at 150 kg ha<sup>-1</sup>. Using equations (10) and (11) for the 80 kg ha<sup>-1</sup> application rate the expected tray mean is  $8\bar{x}_i$  and standard deviation about the mean is  $\sqrt{\frac{8}{2}}\sigma_i$ . The division by  $\sqrt{2}$  accounts for the two rows which together narrow the variability of the averaged mean of the collected data.

Figure 3.9 shows the coefficient of variation calculated for each test method using equation (4). It shows that the  $CV_i$  is lower for the ACCU Spread (Aus) and the ES (Europe) than for the other spread tests at all three application rates. This is because they collect more data; both use two rows of trays and in addition the ACCU Spread (Aus) test has repeated passes before the fertiliser is weighed. Figure 3.10 shows the 95% confidence interval for the industry measure of variation,  $MV_i$ , calculated using equation (5). This means any test will provide  $MV_i$  results that fall within these limits 95% of the time. For the same reasons, the ACCU Spread (Aus) and ES (Europe) have tighter confidence limits.

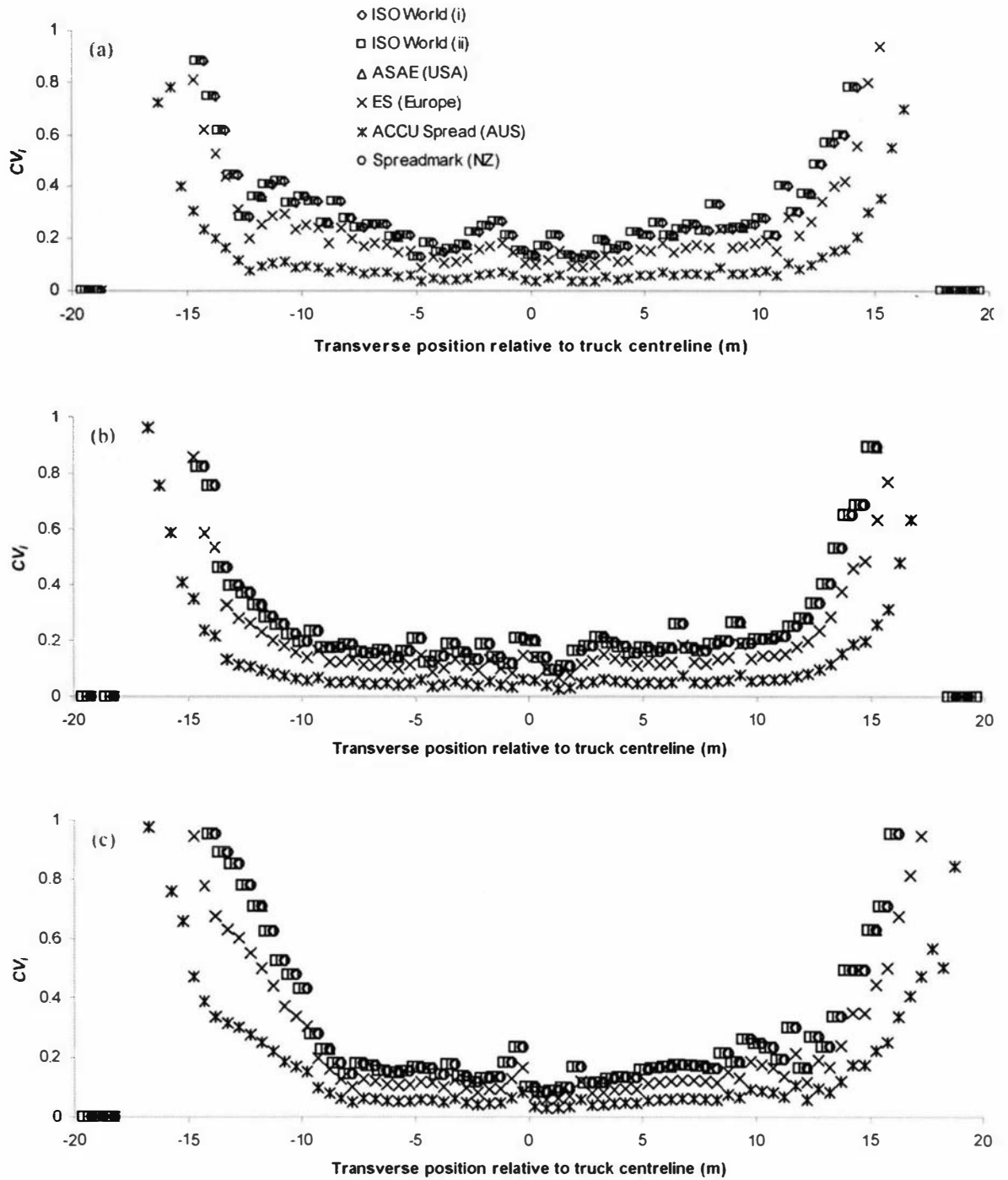
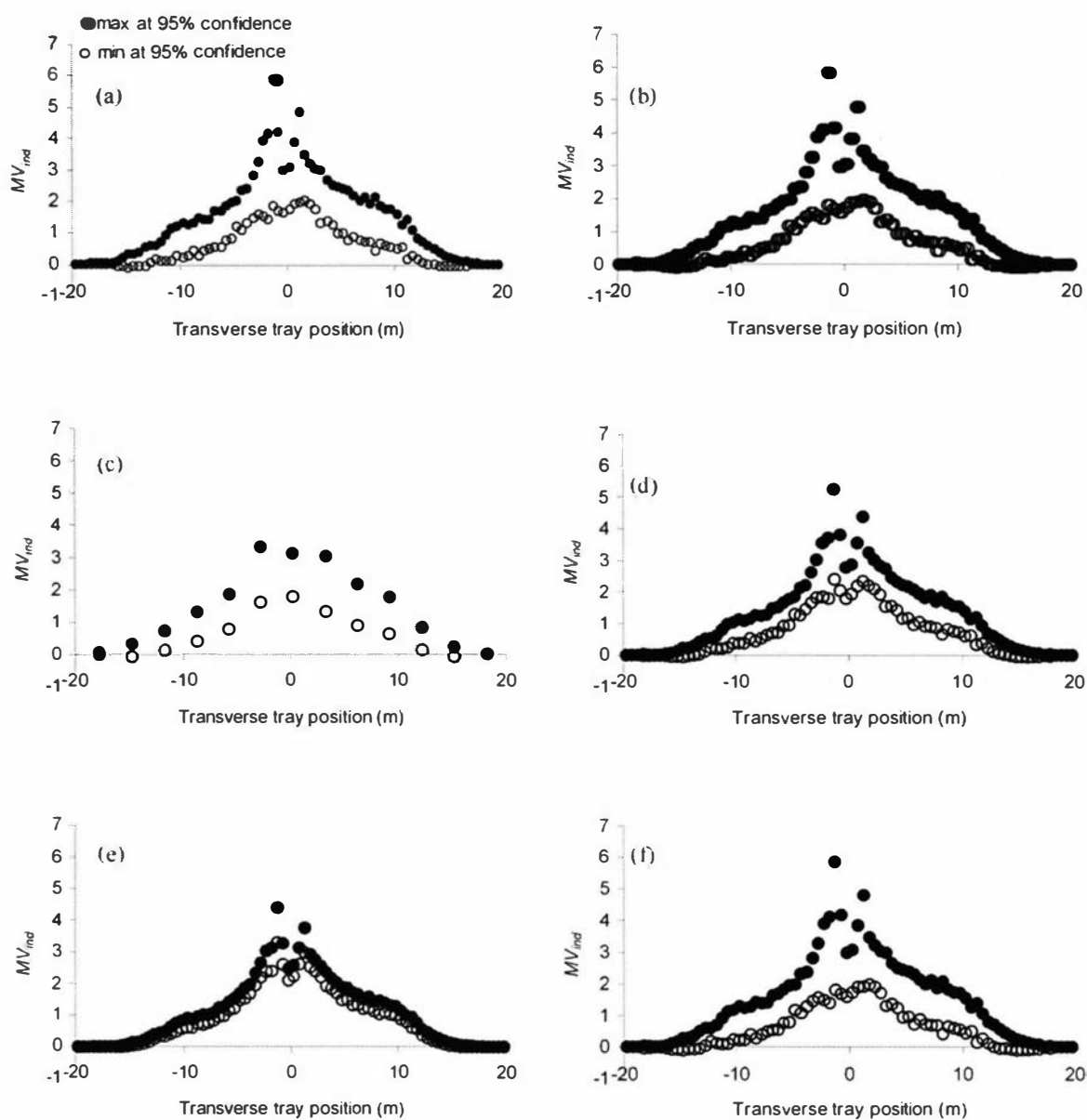


Figure 3.9. Expected coefficient of variation,  $CV_i$  (equation (4)), for all international tests as a function of tray position for test data collected at nominal application rates of (a) 80 kg ha<sup>-1</sup>, (b) 100 kg ha<sup>-1</sup> and (c) 150 kg ha<sup>-1</sup>.



**Figure 3.10a. Industry measure of variation for six international spread tests ((a) ISO(i), (b) ISO(ii) (c) ASAE, (d) ES, (e) ACCU-Spread and (f) Spreadmark as a function of tray position when applying urea at a nominal application rate of  $80 \text{ kg ha}^{-1}$ .**

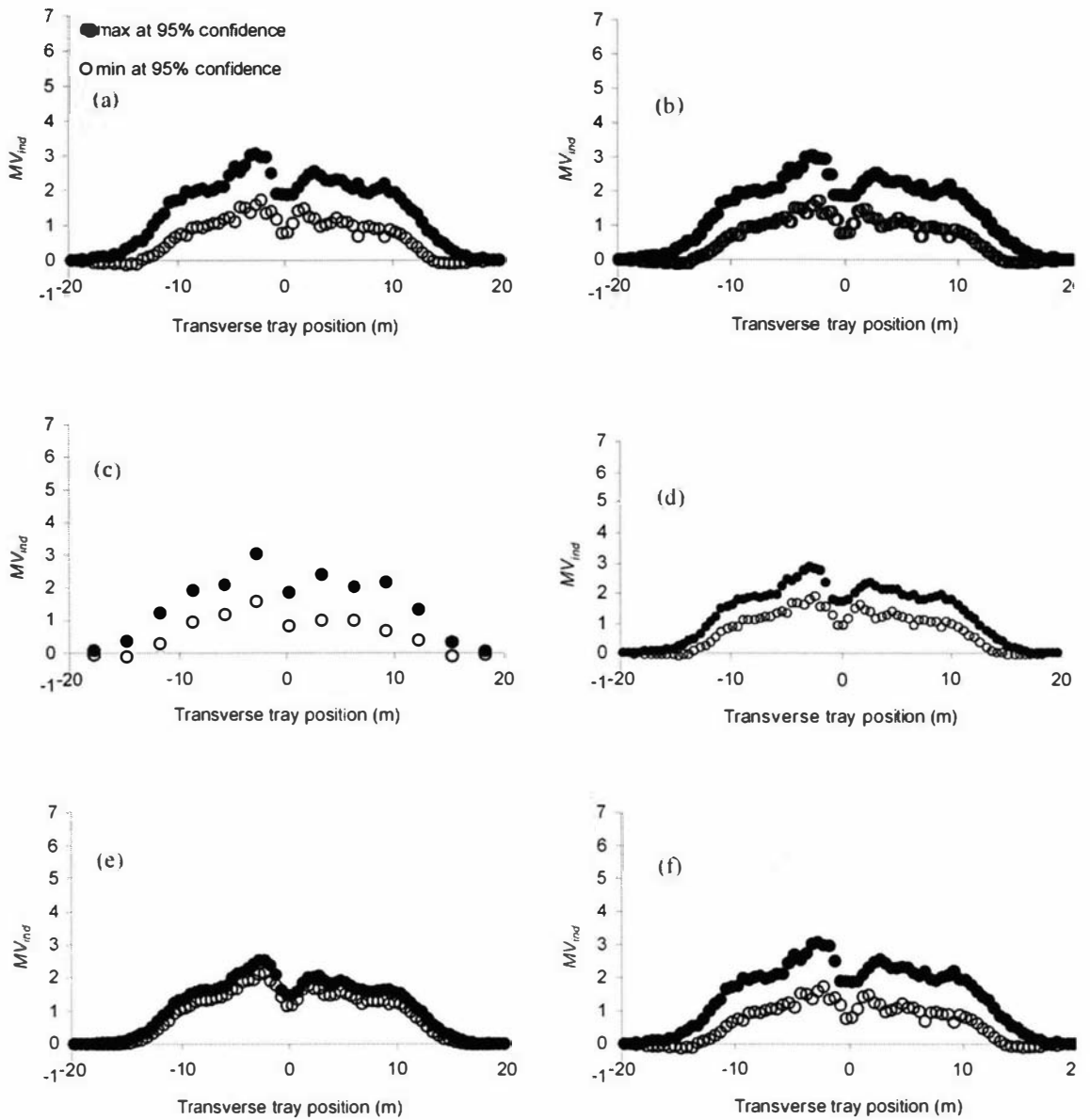
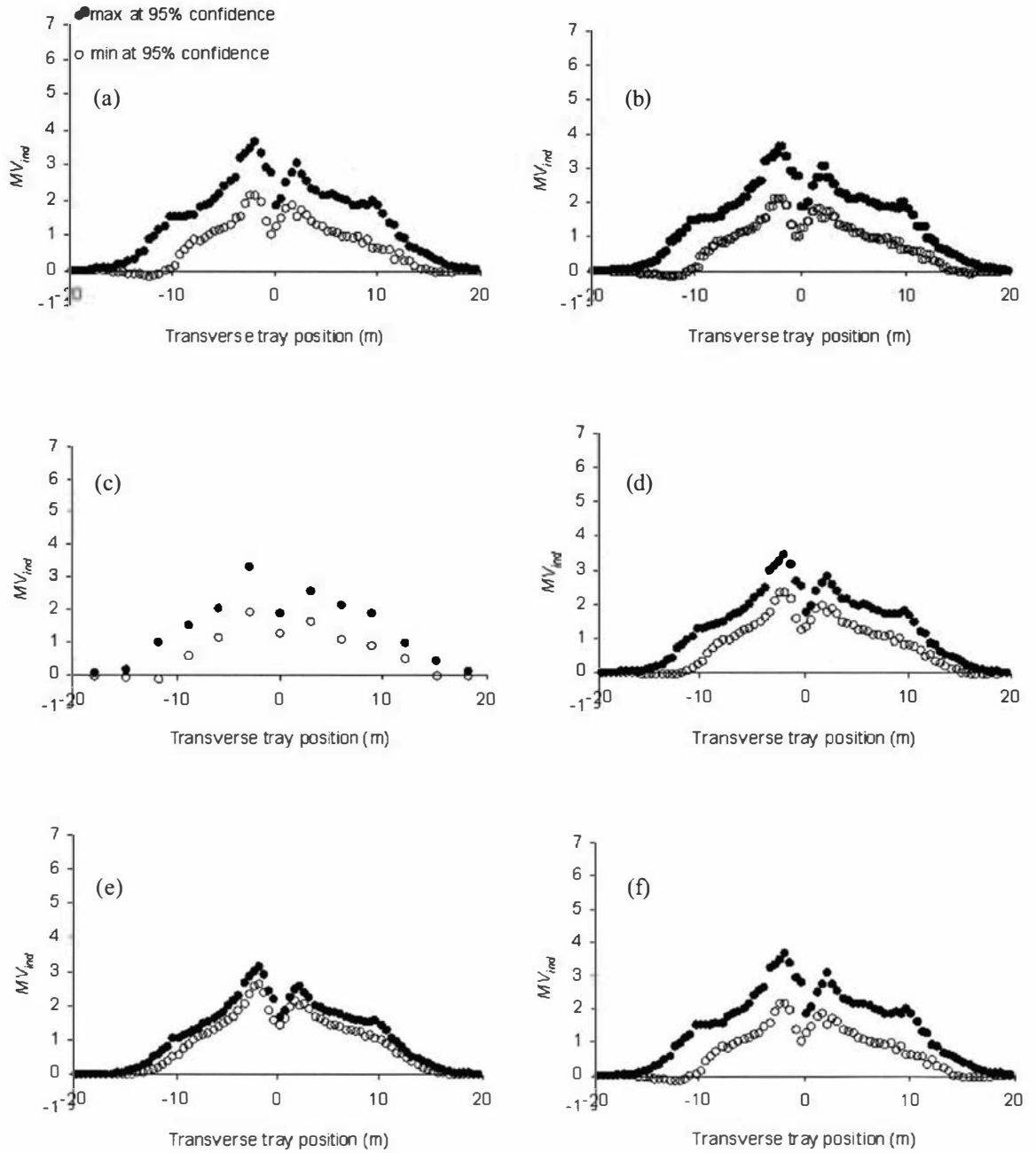


Figure 3.10b. Industry measure of variation,  $MV_i$ , for six international spread tests; (a) ISO(i), (b) ISO(ii) (c)ASAE, (d) ES, (e) ACCU-Spread and (f)Spreadmark as a function of tray position when applying urea at a nominal application rate of  $100 \text{ kg ha}^{-1}$ .



**Figure 3.10c. Industry measure of variation for six international spread tests; (a) ISO(i), (b) ISO(ii) (c) ASAE, (d) ES, (e) ACCU-Spread and (f) Spreadmark as a function of tray position when applying urea at a nominal application rate of  $150 \text{ kg ha}^{-1}$ .**

### **Bout width confidence**

The spreader tests are used to certify the bout width at which the truck can drive between transects across the field be used to spread fertiliser. This paper estimates the confidence in the calculation of this bout width. Each test determines the certifiable bout width by limiting the allowable industry measure of variation across the swath. The choice is somewhat arbitrary, but all tests have adopted the limit of  $MV_i < 0.15$  for nitrogen based fertilisers. Therefore, the confidence in each test method can be estimated by using the sample statistics gathered from the large field trial to determine the probability that  $MV_i > 0.15$  at the outermost edges of the bout. This involves a series of overlapping calculations that simulate the transect driving pattern of the truck. Here, the *round-and-round* (not the *to-and-fro*) driving pattern is examined. Overlapping increases the application rate to give an overlapped mean mass per tray across the bout width of  $\bar{x}_{bout}$ . At the outermost edge of the bout width, the expected fertiliser mass is the sum of that landing on the two trays that overlap at this location,  $\bar{x}_{overlap} = \bar{x}_i + \bar{x}_j$ , the subscripts  $i$  and  $j$  specify the trays numbers that overlap when two transects at a specified bout width are driven by a spreading vehicle. The expected industry measure of variation is the ratio of these two amounts,  $MV_{bout} = \frac{\bar{x}_{overlap}}{\bar{x}_{bout}}$ . Each international test will yield an  $MV_{bout}$  that varies about this expected value according to the sample statistics gathered in the large field trial reported here. The standard deviation at the outermost edge of the bout is  $\sigma_{overlap} = \sqrt{\sigma_i^2 + \sigma_j^2}$  and therefore 95% confidence interval on the measure of variation is  $MV_{bout} = \frac{\bar{x}_{overlap} \pm 2\sigma_{overlap}}{\bar{x}_{bout}}$ . By using the *z-statistic*<sup>7</sup>, the probability that the experimental  $MV_{bout}$  falls above the acceptance threshold  $P(MV_{bout} > 0.15)$  can be calculated. Figure 3.11 plots this probability of an unacceptable  $MV_{bout}$  for the two round-and-round scenarios: the right side of the swath with left overlap and the left side of the swath with right overlap. Both are plotted because the spreader does not spread evenly over both sides of the swath. At low bout widths, there is plenty of overlap and little variation about the mean and hence  $P(MV_{bout} > 0.15) \sim 0$ . At high bout widths, the variability is high compared to the mean and hence  $P(MV_{bout} > 0.15) \sim 1$ . Somewhere in-between these limits is the ideal certifiable bout width for the spreader. The concern here is the confidence with which an international spread test can certify a bout width, rather than the bout width itself. In this respect, the ACCU Spread (Aus) test exhibits the steepest curve which corresponds to the greatest certainty in determining the bout width, followed by the ES (Europe) test. All the other tests except the ASAE (USA) provide the same probability curve. The ASAE (USA) test probability curve has not been calculated because the trays are so far apart they do not overlap at the outermost edges of the bout where the calculations have been performed for the other tests. Instead, the ASAE (USA) method requires that the  $MV_i$  profile across all trays must be plotted for each bout width where the trays overlap. This means bout width statistics can only

<sup>7</sup> The *z-statistic* can be used when  $n > 30$ . Here the sample size equals 36 (Ozgur & Strasser, 2004).

be calculated at intervals of 3.0 m which is less accurate than the other international test methods. Interpolation methods may be used to estimate the full ASAE (USA) swath spread pattern from which the required bout width can be estimated, however these techniques are not explored here. A summary of the 95% confidence intervals for certified bout width when using each international test method is given in Table 3.2. The following section discusses the significance of these probability curves for estimation of bout width.

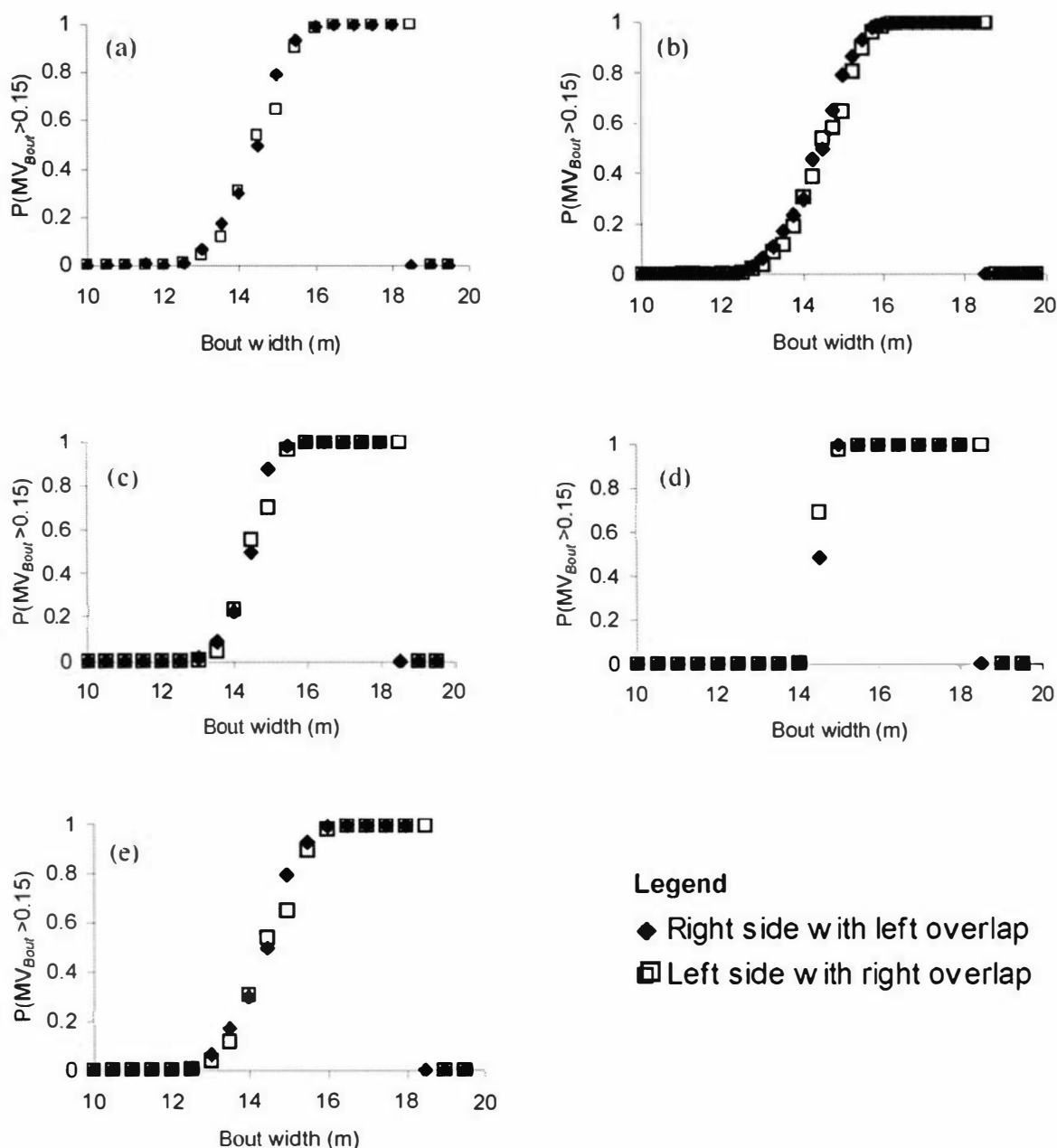


Figure 3.11a. Probability of  $MV_{bout} > 0.15$  as a function of specified bout width for the international spread tests; (a) ISO World (i), (b) ISO World (ii), (c) ES Europe, (d) ACCU Spread (Aus), and (e) Spreadmark (NZ) at a nominal application rate of  $80 \text{ kg ha}^{-1}$ . Results are shown for the two round-and-round overlap scenarios.

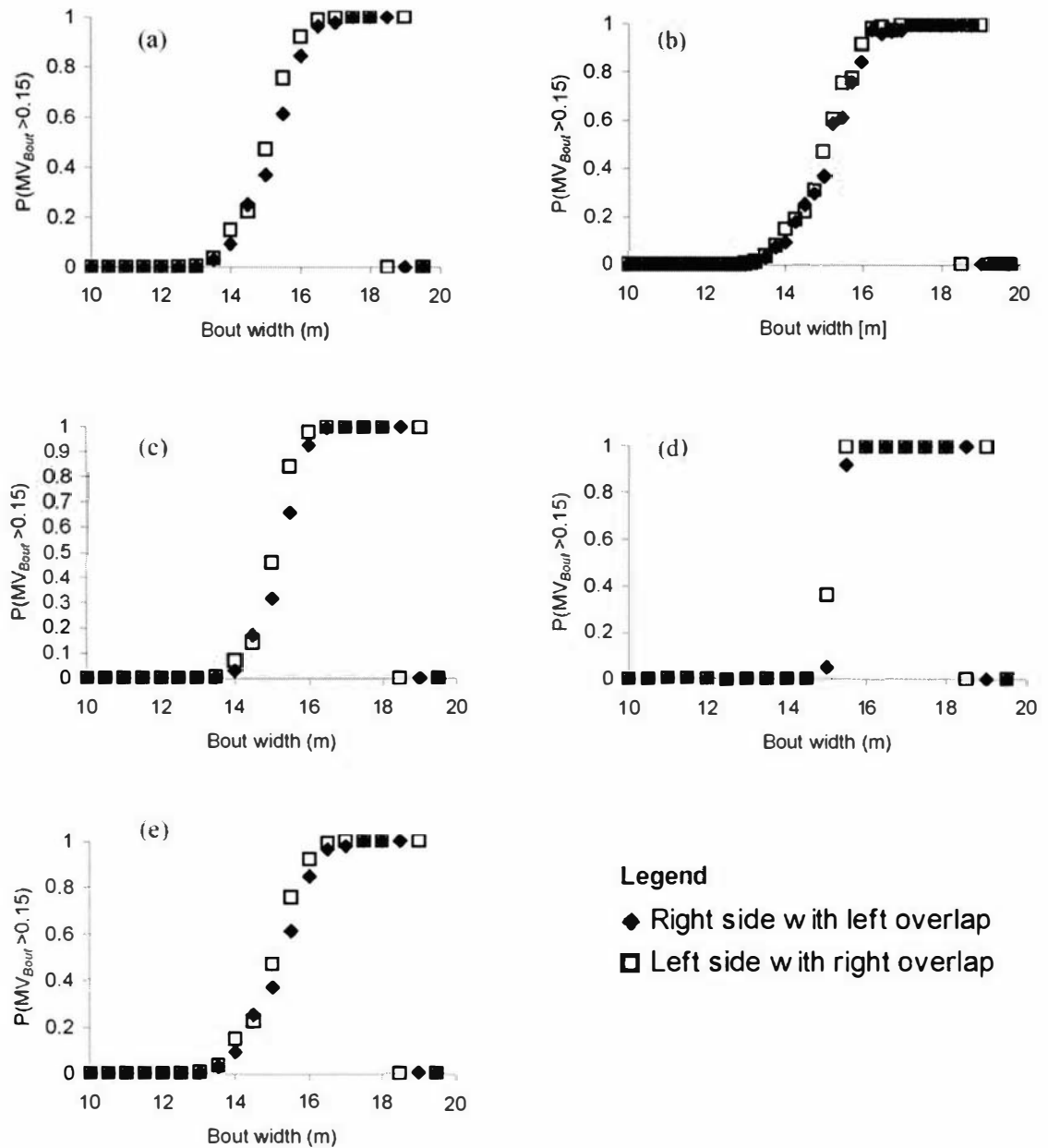


Figure 3.11b. Probability of  $MV_{bout} > 0.15$  as a function of specified bout width for the international spread tests;

(a) ISO World (i), (b) ISO World (ii), (c) ES Europe, (d) ACCU Spread (Aus), and (e) Spreadmark (NZ) at a nominal application rate of  $100 \text{ kg ha}^{-1}$ . Results are shown for the two round-and-round overlap scenarios.

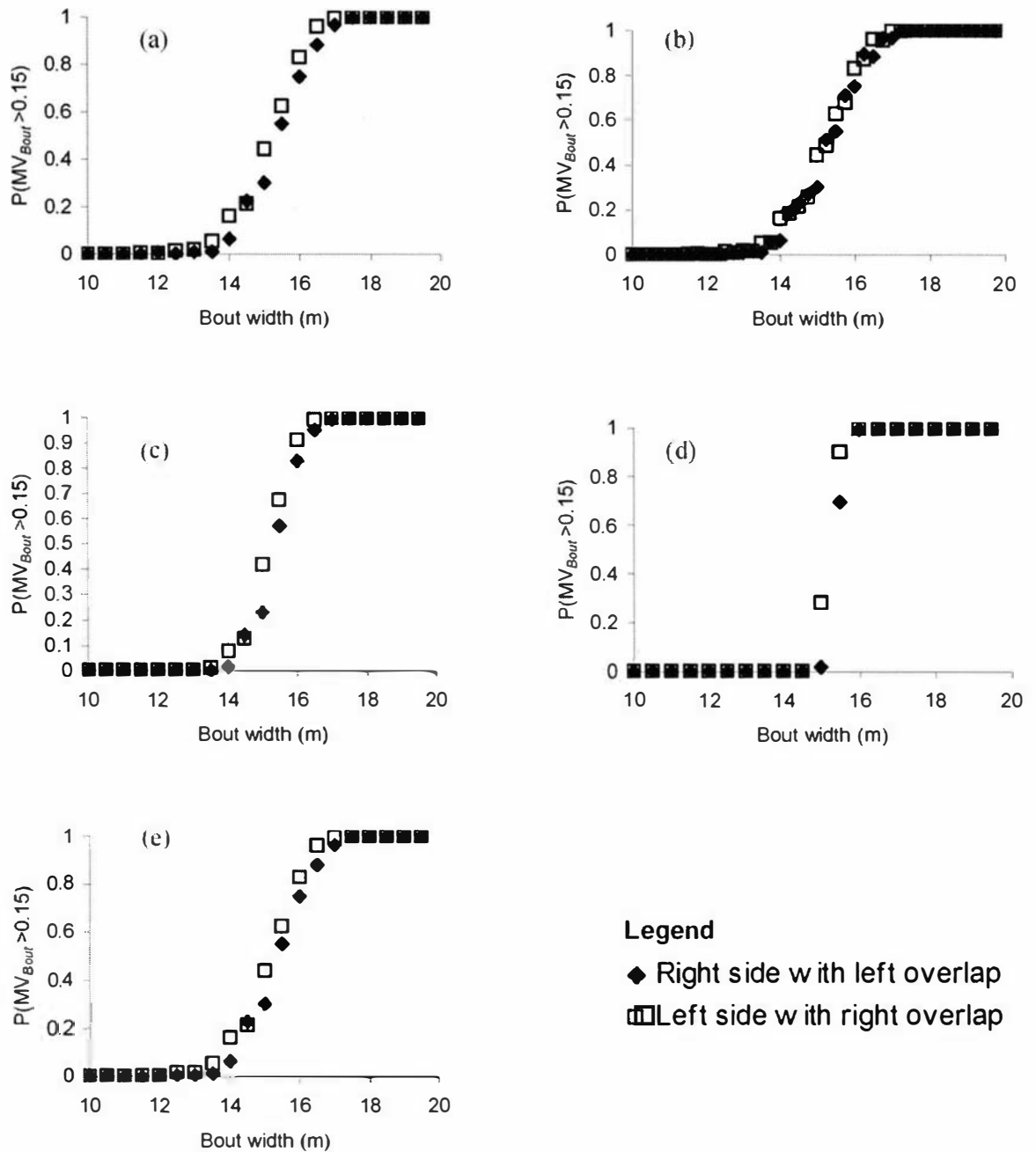


Figure 3.11c. Probability of  $MV_{bout} > 0.15$  as a function of specified bout width for the international spread tests; (a) ISO World (i), (b) ISO World (ii), (c) ES Europe, (d) ACCU Spread (Aus), and (e) Spreadmark (NZ) at a nominal application rate of  $150 \text{ kg ha}^{-1}$ . Results are shown for the two round-and-round overlap scenarios.

**Table 3.3. 95% confidence intervals in specified bout width (m) calculations for international spread test methods when  $MV_{bout} < 0.15$ .**

Test Protocol	Target Application Rate (kg ha <sup>-1</sup> )		
	80	100	150
ISO (i) (World)	13.00 – 16.00	14.00 – 16.50	14.00 - 17.00
ISO (ii) (World)	13.00 – 15.75	13.75 – 16.25	13.75 – 16.75
ES (Europe)	13.50 – 15.50	14.50 – 16.50	14.50 – 16.50
ACCU Spread (Aus)	15.00 – 15.50	15.00 – 15.50	15.50 – 16.00
Spreadmark (NZ)	13.00 – 16.00	14.00 – 16.50	14.00 - 17.00

### 3.4. DISCUSSION

The international spread test methods are experimentally expedient to limit the time and expense to conduct them. This means that the certification of bout width has some level of uncertainty. It is the purpose of this paper to compare the uncertainty inherent between the international test methods. Analysis reveals a number of important considerations when selecting a spread test.

The best performing test is the ACCU Spread (Aus) test, this test has two enhancing features that reduce the variability, these are the use of two rows of collector trays and also multiple spreader passes up to a threshold application rate of 600 kg ha<sup>-1</sup>. For these reasons the ACCU Spread (Aus) test method showed the least uncertainty in both width certification from all those tested here. The ES (Europe) test is the next best performing but is not preferred because rows of trays are adjacent to one-another and are susceptible to the near neighbour effect where the masses landing on nearby trays are dependent due to time dependent machine parameters. Because the ES (Europe) test is a one pass test, the near neighbour effect will be undetected and the time dependency may carry through to the bout width calculations resulting in an erroneous result outside the confidence limits given here. To ensure independence, the rows in an international test method should be spaced as far apart as feasible.

The ISO (i) and (ii) (World) and the Spreadmark (NZ), all produce the same curve for the estimated probability of the industry measure of variability exceeding the threshold,  $MV_{bout} > 0.15$ , at each specified bout width. However, ISO (ii) (World) has higher resolution of these probability calculations because they are performed for bout widths separated by 0.25 m instead of 0.5 m. This work calculates only a single point probability (i.e., at a specified bout width), not a weighted probability based on nearby values. If weighting methods are used, the higher resolution of the ISO (ii) (World) test method will prove more accurate than its sister method.

Most test methods use a 0.5 × 0.5 m tray because it is easy to handle. The ISO (ii) (World) test is different, but its 0.25 × 1.0 m trays have the same area and (it can be assumed) the same variance. The advantage of the ISO (ii) (World) test trays is that the transverse resolution is improved. Therefore, increasing tray size is desirable because it reduces the variance about the mean, but, it must not compromise the transverse resolution of the bout width calculations. Tray area is the same. Tray area impacts on the resolution and the statistics. Tray area affects the variability by the square root of the area ratio between a tray size for which statistics have been collected (1) and a new proposed tray size (2)

$$\frac{\sigma_2}{\sigma_1} = \sqrt{\frac{A_1}{A_2}} \quad [12]$$

For example, if tray size increases from 0.5 × 0.5 m to 0.5 × 2.0 m the standard deviation reduces to half the original value. This assumes normally distributed data with the additional advantage of eliminating <2.0 m periodicities (of the type seen at -3.75 m longitudinal position for the 80 kg ha<sup>-1</sup> data in Figure 3.4. The effect of longer trays is also captured by having multiple passes before the fertiliser is collected. The ACCU Spread (Aus) test does this, where each row is effectively a tray of 0.5 × 4.0 m long for the eight passes at the 80 kg ha<sup>-1</sup> application rate, with the added advantage of guaranteed independence. Practically trays of this size become unwieldy to handle. Therefore, multiple passes are preferred to larger tray sizes.

The ACCU Spread (Aus) test method predicts the certifiable bout width within one tray, or 0.5 m, so is it possible to further improve the accuracy of the bout width calculation? The above analysis method shows that increasing the number of rows, defining a higher threshold application rate and increasing the longitudinal length of the trays will all decrease the expected variability of the test. However, the need to do this depends upon the quality of fertiliser spreading required by the worldwide agriculture industry. Current fertiliser spreaders cannot deliver fertiliser to the accuracy necessary to match geographic information system (GIS) maps obtained from modern harvest and spatial monitoring equipment. In conclusion, the ACCU Spread (Aus) test method is the best at predicting the certifiable bout width. It represents a cornerstone international quality standard upon which further improvements in fertiliser spreading technology can be assessed.

### 3.5. CONCLUSION

A large fertiliser spreading field trial was performed consisting of 18 adjacent rows of 80 trays, each 0.5 × 0.5 m in size with trays removed for the wheels of the spreader. The data was first analysed for time dependent behaviours in the longitudinal direction for trays located at common transverse positions. These time dependent behaviours were detected statistically as a near neighbour effect. The 80 and 100 kg ha<sup>-1</sup> application rates showed no near neighbour effect, but it was observed at 150 kg ha<sup>-1</sup>. This finding illustrates that standard test methods should not employ adjacent rows of trays, which rules out the ES (Europe) test as the preferred method. Instead, rows of trays should be placed as far apart as feasible.

Secondly, the sample mean and variance for all transverse tray positions from the large field trial were used to reconstruct each of the six international spreader tests, both for the 95% confidence limits in the

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expected values obtained from each test, and for the confidence in the bout width calculation. The ACCU Spread (Aus) test method displayed the highest level of confidence in its bout width calculation followed by the ES (Europe) test method. The ISO(i) (World), ISO(ii) (World) and Spreadmark (NZ) tests were all found to be comparable to one another whilst the ASAE (USA) method was poorest because the trays are spaced widely apart across the swath, which, in turn, limits the ability to make accurate point calculations. All test methods can employ interpolation or weighing techniques to improve the accuracy in the bout width calculation, however, these are not investigated here. The calculations show that confidence in the bout width calculation is greater when multiple rows of trays are used, when multiple passes of the spreader are employed and when trays have greater area by being longer in the longitudinal direction. The ACCU Spread (Aus) predicts bout widths to within a single 0.5m tray for urea over the application rates tested. Therefore, it represents the top international quality standard to assess improvements in fertiliser spreading technology.

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## CHAPTER 4

# DEVELOPMENT OF AN IMAGE PROCESSING METHOD TO ASSESS SPREADER PERFORMANCE

### *Paper Reference*<sup>8</sup>

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Lawrence, H. G., I. J. Yule, M.G. Coetzee. (2007). Development of an image processing method to assess spreader performance. Transactions of the American Society of Agricultural and Biological Engineers, 50(2): 397–407. Received 30 August 2006; accepted 5 January 2007

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*Abstract.* Fertiliser spreader testing plays an important part in achieving accurate, uniform application of nutrients to the land; however, current testing methods are often laborious with high levels of manual input required to obtain specific spread characteristic information. This study aimed to review and identify potential techniques and test one that could be incorporated into a spreader testing program. A review of available spreader tests throughout the world showed varying results. Measurement systems requiring a mathematical algorithm to calculate the landing position of individual particles were found to be a quick interpolator of machine performance, but inaccurate. Tray collection, used extensively by quality assurance programs throughout the world is accurate in producing distribution pattern results, however, it is a laborious task especially when analysing multiple spread patterns for variable rate application. An image processing method showed the greatest potential as a rapid analysis and interpretation tool of spread pattern data. A computer program was written to analyse and extract individual particle information from urea fertiliser contained on collector trays during a spreader test. Results indicated that there was a strong relationship between two dimensional particle area and particle mass under laboratory ( $R^2 = 0.991$ ) and field ( $R^2 = 0.988$ ) test conditions. Measurements taken within  $\pm 4$  m of the spreading vehicle had a higher expected error when predicting particle mass which was attributed to a high proportion of particles with a cross-sectional area less than  $1 \text{ mm}^2$ . High levels of expected error in field results indicated that particles need to

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<sup>8</sup> This chapter contains some changes to the published paper resulting from examiner emendations.

be greater than 1 mm<sup>2</sup> post spreading if the method was to accurately predict an entire distribution pattern of a fertiliser spreader. However, the method was found to accurately calculate size guide number and uniformity index of the collected sample.

**Keywords.** Fertiliser; application equipment; image processing; particle identification; spreader test; spinning disc spreader.

#### **4.1. INTRODUCTION**

It is important for both farmers and contractors to ensure correct placement of fertiliser is achieved. To guarantee a farmer obtains these results, fertiliser must be placed where intended and at the correct rate by a spreading vehicle. In order to achieve this, a spreading contractor must ensure that the spread widths and rates proposed are achieved. Spreading widths and application rates can only be verified through spreader testing. Fertiliser spreader testing has been widely used throughout the world to understand the distribution performance of fertiliser spreaders in the field. ISO standards state that the aim of testing full width solid fertiliser distributors is to first, fix the variable conditions of laboratory testing, and secondly, give guidance for field test conditions. Two mandatory tests identified by ISO standards are performed in order to understand the distribution performance of a fertiliser spreader; these are: a transverse test, measuring the shape of the distribution pattern and a longitudinal test, measuring the uniformity of distributed material.

The information generated from the test is used to assess whether or not the application accuracy meets legislative or quality assurance requirements set by governing bodies. Standardisation bodies such as the International Standards Organisation (ISO) and the American Society of Agricultural and Biological Engineers (ASABE) have particular protocols that are to be followed when testing spreaders. Other governing bodies around the world have based testing protocols on these standards. Currently, all testing protocols are based on the tray weighing measurement system.

Although the tray weighing system is effective in calculating the overall dispersion of material the method often fails to capture detailed particle characterisation information that can assist in the wider understanding of fertiliser spreader dynamics. The aim of the study was to investigate alternative methods of testing fertiliser distribution accuracy including the ability to obtain particle characteristic information from spread material. This is useful in providing a wider understanding of the ballistic properties of the spread material and dynamic behaviour of various spreader types.

## **4.2. BACKGROUND**

### ***Fertiliser distribution parameters measurement***

A number of physical attributes related to the fertiliser distribution system can cause significant changes in both the width and uniformity of a spread pattern. Olieslagers et al. (1996) described the necessities to model fertiliser distribution as the interaction of spreader settings, particle characteristics and the environment (Figure 4.1). These factors require measurement in order to fully understand and analyse spreader performance.

Particle characteristics have the single biggest effect on fertiliser “spreadability”. The main physical attributes measured in international fertiliser spreader testing programs include: particle mass, particle size, moisture content, bulk density, particle density, granule hardness, particle shape, surface texture and angle of repose. Particle mass from a spreader test is currently collected in plastic trays of a size defined by the regulatory body administering the testing program. Only the collective weight of individual particles contained on a collection tray is used to produce a mathematical representation of distributed material; this information is also used to calculate expected application variation by overlapping the spread pattern on itself at defined bout widths. Sieve analysis is commonly used to measure particle size distribution in a fertiliser sample prior to spreading. A sieve analysis is taken from a bulk fertiliser sample to measure the physical characteristics, typically these measurements include: the size guide number (SGN); uniformity index (UI) and bulk density (BD). The SGN is a measure of the average particle size, the UI calculates the uniformity of the product and the BD measures the density of the product. SGN and UI data are useful to an operator to understand the effect of product characteristics on the spread pattern achieved (Table 4.1). SGN and UI values are also used to predict how well two products will mix together (Table 4.2); the blending of fertilisers is becoming increasingly important, especially with the increased use of trace elements.

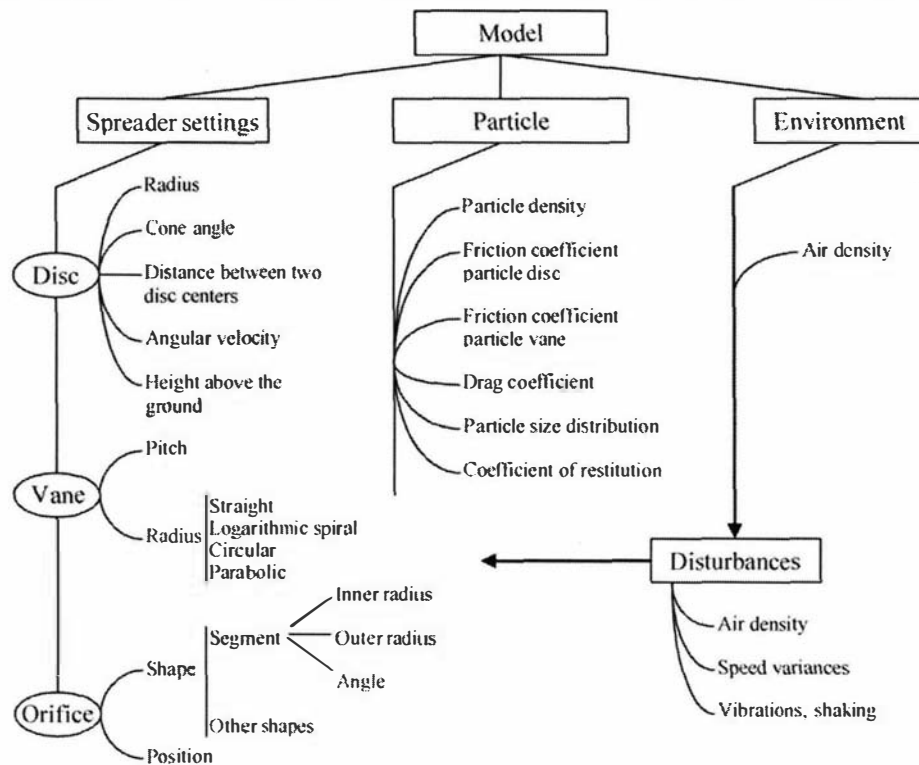


Figure 4.1. Model parameters used for calculating the distribution pattern of a centrifugal distributor

(Reproduced from Olislagers et al., 1996).

Table 4.1. SGN and UI ranges used to identify the effect on spread pattern from a fertiliser spreader.

SGN	UI	Material Class	Effect on Spreading
< 150	< 20	Fine	Narrow swath width, pattern affected by wind
250 – 350	20 – 60	Medium	Desirable range. Even spreading should be possible with any spreader.
> 350	> 50	Coarse	Wide swath possible but hollow spread pattern likely. Spreader design important.

Due to the increased use of blended fertilisers it is extremely important that all nutrients of a described blend receive uniform application. Each component of a blended fertiliser has specific characteristics (granulometry, bulk density, shape, angle of repose etc.) and there is often a risk of particle segregation (Tissot et al., 1999). For this reason uniform chemical distribution cannot be guaranteed from fertiliser blends. Tissot et al. (1999) described a method of chemical analysis at 6 locations along a transverse distribution line to measure the distribution accuracy of blended fertilisers. This method involved taking the contents of 6 individual trays and determining the NPK ratios of each; from these results, individual distribution patterns for N, P and K could be developed with results indicating that several blended fertilisers were able to be

spread uniformly. Miserque et al. (2005) concluded from similar work that significant segregation was mainly due to differences in particle density and size with particle shape having only a limited impact on segregation. Table 4.2 identifies specific ranges of SGN and UI values of individual fertilisers where blending compatibility is seen as good, moderate and poor.

**Table 4.2. Prediction of distribution segregation based on SGN and UI between two fertilisers to be blended**

Difference between SGN or UI values for each blend constituent	Compatibility for blending
< 20	Good Compatibility
20 – 40	Moderate compatibility, some segregation likely
> 40	Incompatible

### ***Review of spreader testing methods***

Five tested and documented methods of testing fertiliser spreader performance were reviewed. These were tray testing, mathematical calculation, cylinder measurement, optical measurement and image processing. Each method was evaluated based on its ability to measure the parameters required to accurately assess spreader performance. The tray measurement system is the most widely used throughout the world and is recognised by the ISO standard 5690/1 (1985) and ASAE standard S341.2 (1999). However, significant variation occurs between methods in terms of tray frequency and spacing. For example, ISO standard 5690/1 (1985) requires a continuous tray spacing that is wide enough to cover the entire distribution pattern, whilst the ASAE standard S341.2 (1999) requires a minimum of only 10 trays to be used evenly distributed over the transverse distribution width. Lawrence et al. (2006) described the effects of tray frequency, tray spacing and tray size required to obtain accurate results from various international transverse test methods, however, The influence of these factors especially with regard to longitudinal testing is not well documented. Longitudinal testing is becoming increasingly important with the adoption of variable rate application systems in order to measure the ability to change rate in real time whilst maintaining spread pattern shape. The method is very labour intensive unless an automated system, such as the large testing hall at the Agricultural Engineering Research Centre, Bygholm, Denmark is used. The results achieved through tray measurement are accurate in determining the mass of fertiliser distributed but provide no information in order to explain spread pattern variation in terms of particle size, density and shape, etc.

Many mathematical models have been developed to calculate, rather than measure the distribution pattern from a fertiliser spreader (Aphale et al., 2003; Cunningham & Chao, 1967; Griffis et al., 1983; Olieslagers et

al., 1996; Patterson & Reece, 1962; Pitt et al., 1995). These mathematical models evaluate landing positions of spread material based on particle trajectories. This allows a greater understanding of the interaction between fertilisers and spreaders. However, the accuracy of using such models to define a distribution pattern of various spreaders varies significantly due to machine design. Aphale et al. (2003) aimed to validate previous mathematical models given in the literature, however, they found that there was significant variation between the analytical predictions for the distance travelled and the experimentally measured values. At 540 rpm, the variation in actual particle landing positions ranged between 0 and 42% with an average variation of 20%. The model predicted landing positions better at 810 rpm with an average variation of 13% from the actual landing position. Olieslagers et al. (1996) also found a significant difference between the predicted spread pattern and the actual experimental distribution. Tissot (1995) concluded that the use of equations of motion was not satisfactory when being used for predicting a fertiliser distribution pattern in the field due to the difficult nature in modelling the interaction of several particles on a single vane in one instance. Therefore, this method would not be appropriate for accurately predicting the distribution performance and is more useful for obtaining a better understanding of the effect of machine parameter changes on spreader distribution which should be incorporated into machine design.

A cylinder measurement method reported by Reumers et al. (2003) used a series of cylinders around the spreader in order to collect spread material. Mathematical algorithms were then used to calculate actual landing positions based on particle characteristics and particle volume collected in each cylinder. Like the mathematical calculation method, the cylinder method failed to accurately predict landing positions of individual particles. Reumers et al. (2003) concluded that it was possible to draw correct qualitative conclusions about the influence of certain parameters of the static distribution pattern using the cylinder test facility, however, it was not possible to predict distribution patterns with sufficient accuracy to replace spreading hall measurements completely.

A ballistic model using optical sensors to measure particle size and velocity reported by Grift & Hofstee (2002) is simpler than that described in mathematical models and did not require machine parameters except initial launch height to be measured. Results indicated that the optical sensor arrangement produced an excellent indication of the relative dispersion of fertiliser material behind the spreader; however, the system did not accurately assess the applied rate, as 17% of the measured particles were discarded due to read error

from the optical sensor. Vangeyte & Sonck (2005) and Villette et al. (2005) report similar methods using a captured blurred image to measure initial particle velocity off a spinning disc, this information was used as the basis to predict spread pattern via a mathematical model. Vangeyte & Sonck (2005) concluded that although there were differences between simulated and calculated spread patterns they were small. It has been proven that using a combination method of measured velocity and mathematical calculation can give an indication of relative distribution pattern for a centrifugal spreader, however the ability to measure variation caused by longitudinal effects are eliminated.

Hensel (2003) described a methodology for mapping the distribution of fertiliser in the field. The method was based on an image processing system which enabled images taken of the field surface to be analysed. The method used an ATV to collect geo-referenced images of fertiliser distribution information. Results showed that particle detection accuracy of the system was 100% on freshly cultivated soil. However, when crop was introduced, the detection rate decreased significantly as some particles were partially covered by the crop. It is reported that the rate of detection was significantly correlated to leaf area index concluding that to obtain a particle detection rate of above 95%, the total soil-covering leaf index had to be below 5%. Miserque et al. (2005) used a similar method to measure physical parameters of collected fertiliser samples from field trials under lab conditions. They concluded that they were able to successfully identify individual components of blended fertiliser across the distribution pattern by analysing individual particles for measures of elongation, roughness and roundness.

The use of image processing and machine vision to analyse parameters associated with the measurement of fertiliser distribution showed the most potential to be developed into a system that could be adapted into current measurement systems. The literature suggests that using image processing can potentially give the same information as that obtained from the tray measurement technique without the need for manual weighing of individual samples. There is also the potential to extract a wider range of information from processed images including; SGN and UI calculations, and chemical distribution of blended fertilisers.

#### ***Development of image processing method***

Based on a review of potential testing methods a system was developed to evaluate the performance of fertiliser spreaders using a hybrid technique combining the image processing and tray testing methods. Image processing, more commonly known as vision systems, have proven to be successful in applications ranging

from routine inspection of food products, to complex vision systems that control machines. Vision systems have found wide application in medical science in counting and auto-recognising cells and particles from microscopic imagery whilst routine inspection of quality based attributes like size, colour and shape have found wide application in food products. Fertiliser spreader testing is most commonly undertaken outside in calm weather conditions; therefore a changing light environment is often encountered. This was seen as the major difference for the development of the method compared to vision systems that are used in laboratories and factories where controlled lighting conditions can be obtained. The developed system was required to: classify fertiliser particles within an image; perform a descriptive analysis of identified particles; record descriptive data and perform unsupervised classifications of multiple images. A vision system typically relies on the capture, extraction and measurement of information that is relevant for the end user.

There are a number of key elements that need to be considered in the identification and extraction process. Nazar et al. (1996) used five general steps: image acquisition, pre-processing, segmentation, extraction, and representation of the characteristic parameters, whilst Du and Sun (2004), used a simplified three prong approach, this being noise reduction by median filter, thresholding based segmentation, and edge detection.

Pre-processing is required to remove image ambiguities such as background heterogeneity and touching or partially overlapping particles (Nazar et al., 1996). There are many filters designed to eliminate these elements from an image. Nazar et al. (1996) described a Fourier high-pass filter to improve the brightness homogeneity of an image when using image processing to identify powder particles, this filter has high relevance when trying to identify small fertiliser particles that have been broken post spreading.

Following pre-processing images are required to be classified and extracted using computer segmentation. Segmentation approaches are categorised into four classes: pixel based segmentation, area based segmentation, edge based segmentation and physics based segmentation. Nazar et al. (1996) stated that the most important extraction information concerns for particles are size (2D area and major and minor particle axis) and shape (eccentricity and form factor). Banta et al. (2003) used a method of scanning a large number of particles in a single frame to estimate particle volume based on 2D area. The method used standard pixel based features (projected area, edge length, and particle centroid) to predict particle mass which were then used to predict yield of a lime sample. Calibrated scaling factors were used to transform pixel information

into millimetre units allowing particle length and width to be computed based on the major and minor axes. The method predicted the mass of a batch of lime particles to within  $\pm 2\%$  ( $R^2=0.91$ ). Cruvinel et al. (1999) found that the error in estimating rain droplet size using a similar method to Banta et al.(2003) varied from 0 to 1.5% and explained the error as due to the irregularity of the collecting medium, however, droplet size uniformity and distribution could be obtained in spite of some error in absolute size measurements. When using 2D imaging to measure particle volume Banta et al. (2003) concluded that it was not critical to predict volume of single particles with absolute accuracy. What is really needed is a statistical estimation of volume across the specified range of particle sizes. If a measurement consisted of an adequate sample size, the central tendency of the random variable, volume, should allow an accurate estimate of aggregate sample statistics.

### **4.3. METHODOLOGY**

A process methodology was written based on the fundamental principles of image processing theory. The process involved performing a transverse fertiliser spreader test using urea fertiliser collected in standard collector trays. Images of fertiliser particles landing on the 500 x 500 mm collector trays were captured using a digital camera. A pre processing filter and particle analysis tool were developed in the LabView 7.1 programming environment (National Instruments, 2004) to extract and analyse particle information.

#### ***Image Acquisition***

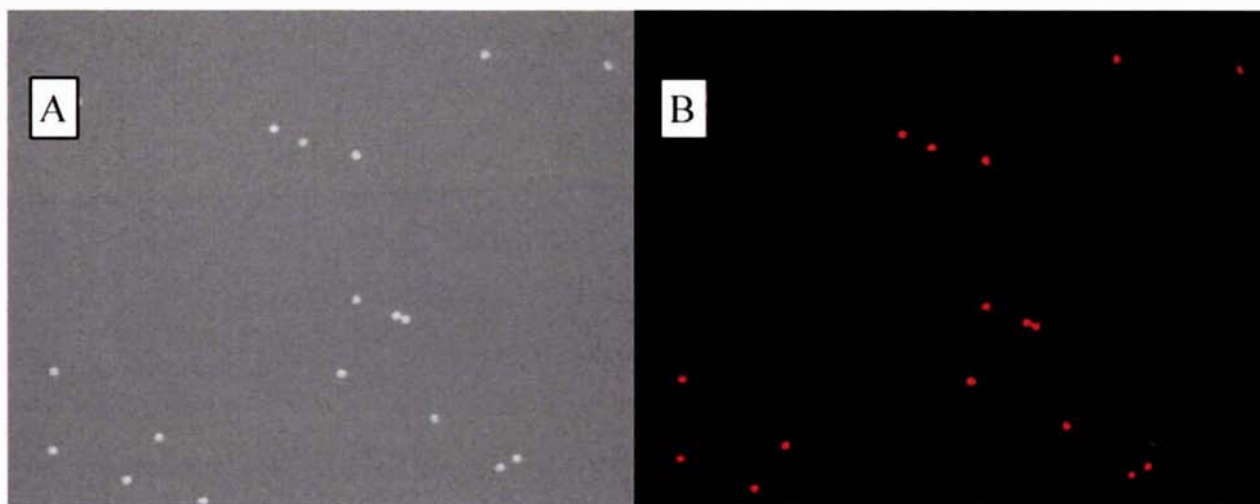
Images of fertiliser particles retained in ISO standard size (500mm x 500mm) collector trays were required to be captured in order to evaluate the image processing method. The hardware needed to be relatively cheap in order for the developed system to be a viable option for fertiliser spreader testers to use in the field. Therefore the components used were all readily available at local retail stores. The digital camera used was a Sony DSCP10, a five Mega pixel camera with three time's optical zoom. The camera was mounted on a Manfrotto tripod set 0.9 m above the collector tray surface. The tripod head was inverted to capture images pointing towards the tray surface. Images were collected on board using 128 MB Sony Memory stick storage card, captured photos were taken in sequential order, therefore no renumbering of images pre-processing was required. Captured images had a spatial resolution of 72 pixels per inch (ppi) and a radiometric resolution of 8 bits.

### ***Process Algorithm Development***

A program was written in LabView 7.1 (National Instruments, 2004) to post process and analyse filtered images. Calibration images were captured in a controlled laboratory environment whilst trial images were captured in the field where light conditions were variable. All images were therefore pre processed to reduce variations in light intensity between images. A Gaussian filtering technique within the LabView environment was found to remove the most background noise in this study, this filter attenuates the variations of light intensity in the neighbourhood of a pixel (National Instruments, 2004).

Following filtering, the raw image (Figure 4.2a) was required to be split into two classes (background and particles) using image segmentation techniques. Predominately, the colour spaces used for image segmentation are RGB, HSI and its variants, HSL, HSV and HSB. Because captured images varied in light intensity, a robust algorithm based on the images attributes needed to be configured in order to identify objects in sequential images. The HSI model, which is commonly used in image processing to separate both colour and intensity information from an image was used in this study. Bjurström & Svensson (2002) describe the HSI model as the colour according to wavelength (Hue), the amount of colour (saturation) and the amount of light in the colour (intensity). The segmented image was converted to a binary image (Figure 4.2b), used to extract data from the segmented image.

Images were filtered further to remove remaining noise and split touching particles using morphological and geometric methods. Particle separation was achieved by using the “Separate objects” function in LabView (National Instruments, 2004). The tool used a 5x5 structuring element to erode pixels between touching particles. This method was found to be sufficient in splitting all touching particles over a wide range of particle sizes. Particles that had significant overlap and could not be split using the tool were not removed from the image as this would reduce overall tray mass and lead to erroneous results. However, characterisation statistics (e.g. area, axis length etc) for the particle were discarded from the created excel database in order not to influence particle characteristic results.



**Figure 4.2. (a) Image of fertiliser particles with blue colour plane extracted. (b) Binary image of fertiliser particles with noise removed.**

The pixels in each image were converted to SI units (mm). Calibration between pixels and mm was achieved by placing a 97 x 97 mm square disc inside each collector tray prior to image capture. The square was easily distinguished from the rest of the image, characteristics of the shape were pre-loaded and the conversion between pixels and mm applied to the entire image allowing particle information such as 2D particle area and major axis length to be represented as mm<sup>2</sup> and mm respectively.

Particle characteristics were extracted on each individual particle within the image. This same principle as used by Banta et al. (2003) was applied in this study to convert the 2D area of particles contained in a collection tray to tray mass using a calibration equations specific to the fertiliser type used. Individual particle area, ellipse major and minor axis and shape type factor were also recorded to give estimates of particle size and uniformity could be made. Attributes of each particle were collated in an Excel spreadsheet (Microsoft Corporation, 2002).

### ***Test of Hypothesis***

The image processing method discussed could be applied to accurately analyse required particle information for the measurement of a fertiliser distribution pattern from a broadcast spreader. However, in order to validate this method three concept tests were developed to identify the measurement accuracies of the method. The first test conducted was used to evaluate the ability of the method to identify fertiliser particles of various sizes. The second test was to define the calibration of 2D particle area and particle mass, whilst the

third test evaluated the performance of the method to predict overall spread pattern shape, size guide number (SGN), uniformity index (UI) and coefficient of variation (CV) at varying bout widths. Captured images for tests 1 & 2 were conducted under lab conditions where ambient lighting was controlled. Images captured in test 3 were taken in the field immediately after completing a transverse spreader test. In all tests the same camera and tripod setup was used.

**Test 1** - A particle detection test was conducted to determine the accuracy of identifying urea fertiliser particles of different size using image processing. A random sample of particles was split into seven size categories using a series of sieves (Table 4.3). A 30 particle sample was taken from each sieve aperture; no particles were contained in sieve apertures greater than 5.8 mm and therefore were not able to be evaluated. Minimum numbers of particles were found in the Pan and 0.4 mm sieve apertures and therefore were measured, the majority of particles (> 60%) were found in sieve apertures between 2.8 and 3.35 mm.

**Table 4.3. Proportion of urea particles contained in sieve apertures between 0 and 4 mm prior to spreading.**

Sieve Aperture (mm)	Pan	0.4	1.0	2.0	2.8	3.35	4.0
% Urea contained	0.0%	0.2%	3.4%	17.2%	30.4%	30.5%	18.3%

Collected particle distribution information was used to calculate the SGN and UI of urea prior to spreading; these were 333 and 49 respectively. This indicated that the product was relatively uniform (Table 4.3). The 30 particles selected were stored in individual containers, five repetitions of each test at each sieve size was completed. Each set of particles were tipped randomly into the test tray and a digital image captured using a tripod at a set height. The images were filtered and processed using the software developed in the LabView (National Instruments, 2004) environment. This test looked solely at the number of particles of different sizes that were able to be identified using image processing.

**Test 2** – Identified particles from each image were two dimensional, therefore, only the 2D projected surface area of the particle was known. Individual particle area was required to be converted into individual particle mass in order for the method to be successful. The test involved capturing calibrated images of particles contained in each sieve aperture (Table 4.3). The average particle area ( $\text{mm}^2$ ) was acquired from the image processing method and compared to the overall mass of the sample measured using an electronic balance. Regression analysis was used to find the relationship between particle area ( $\text{mm}^2$ ) and particle mass (g). The aim of this test was to develop a robust algorithm that could be used to convert 2D projected surface

area to particle mass for urea particles of all types of geometry.

**Test 3** – A matrix of 1440 0.5 x 0.5 m trays was used to collect fertiliser distribution data from a Transpread centrifugal twin disc spreader. The tray matrix consisted of 18 transverse and 80 longitudinal rows laid out edge to edge on a flat tar sealed surface. Data from three transverse and five longitudinal rows were analysed using the image processing method described, these columns and rows were at equal intervals throughout the tray matrix (Figure 4.3). Each tray sample was collected in a sealed plastic bag and weighed and analysed in a laboratory. A manual sieve using the same apertures described in Table 4.3 was performed on individual tray samples to calculate particle distribution. The output information from the particle analysis was used to calculate the approximate mass of particles collected in each tray, the distribution of particle sizes and the overall distribution pattern of the fertiliser spreader. This analysed information was compared to that of the sample bags collected during field testing.

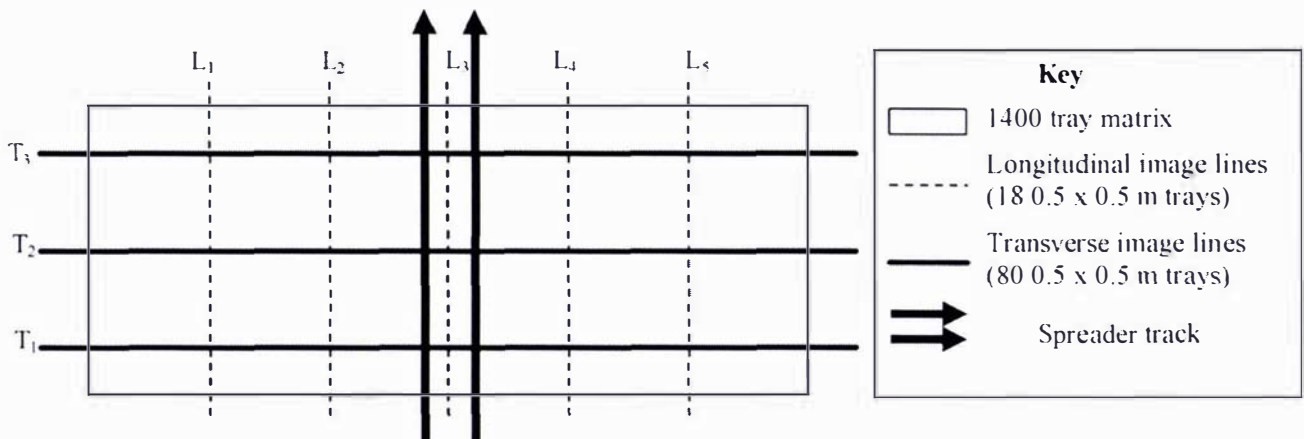


Figure 4.3. Transverse and longitudinal transects taken for image analysis from a 1400 tray matrix used for a fertiliser spreader test.

#### 4.4. RESULTS

##### Test 1

Results showed that particle identification rate was related to particle size. Over 90% of particles were identified when they were contained in a sieve aperture of greater than 1.0 mm. Particles contained in the Pan and 0.4 mm sieves were only identified at levels of 72.7% and 76.7% respectively (Table 4.4). The majority of urea particles were collected in sieve apertures of size 1.0, 2.0, 2.8, 3.35 and 4.0 mm making up 3.4, 17.2,

30.4, 30.5 and 18.3% respectively of total particles in a sample. Particles contained in sieves below an aperture of 1.0 mm were harder to identify than larger particles. However, prior to spreading, this low identification rate did not have a huge influence on output results for urea as only 0.06 % of particles were contained in sieve apertures of less than 1.0mm. This indicates that an overall urea particle identification rate of 99.2% could be achieved.

**Table 4.4. Identification rates of 30 urea particles using image analysis contained in sieve apertures between 0.0 and 4.0 mm<sup>2</sup>.**

Sieve aperture	Average	S.D
Pan	72.7%	11.8%
0.4	76.7%	18.3%
1.0	91.3%	7.2%
2.0	98.7%	2.7%
2.8	100.0%	0.0%
3.35	98.0%	2.7%
4.0	99.3%	1.3%

### Test 2

In total over 2600 individual particles contained in sieve apertures between 0.4 and 4 mm were used to analyse the relationship between particle area (mm<sup>2</sup>) and particle mass (mg). Individual particles on average ranged between 0.20 to 58.60 mg and 0.55 to 18.81 mm<sup>2</sup> for particle mass and area respectively (Table 4.5).

**Table 4.5. Average particle area (mm<sup>2</sup>) and particle weight (mg) contained in sieve apertures between 0.4 and 4.0 mm.**

	0.4	1	2	2.8	3.35	4
Total Particles	511	468	646	536	344	130
Average Particle Mass (mg)	0.20	3.78	12.09	23.45	36.80	58.60
Average particle area (mm <sup>2</sup> )	0.55	3.62	7.31	10.28	13.46	18.81

Regression analysis was used to calculate the relationship between particle area and particle mass between the minimum and maximum particle sizes obtained from sieve sampling (Table 4.5). A third order polynomial was found to give the best fit for the data range ( $R^2 = 0.991$ ) (Figure 4.4). The regression equation obtained from the data set [1] was used to calculate particle mass from images taken from field trials. The standard error in predicting particle mass from particle area calculated from calibration results was 4.07 mg.

$$y = -0.008x^3 + 0.330x^2 - 0.231x \quad [1]$$

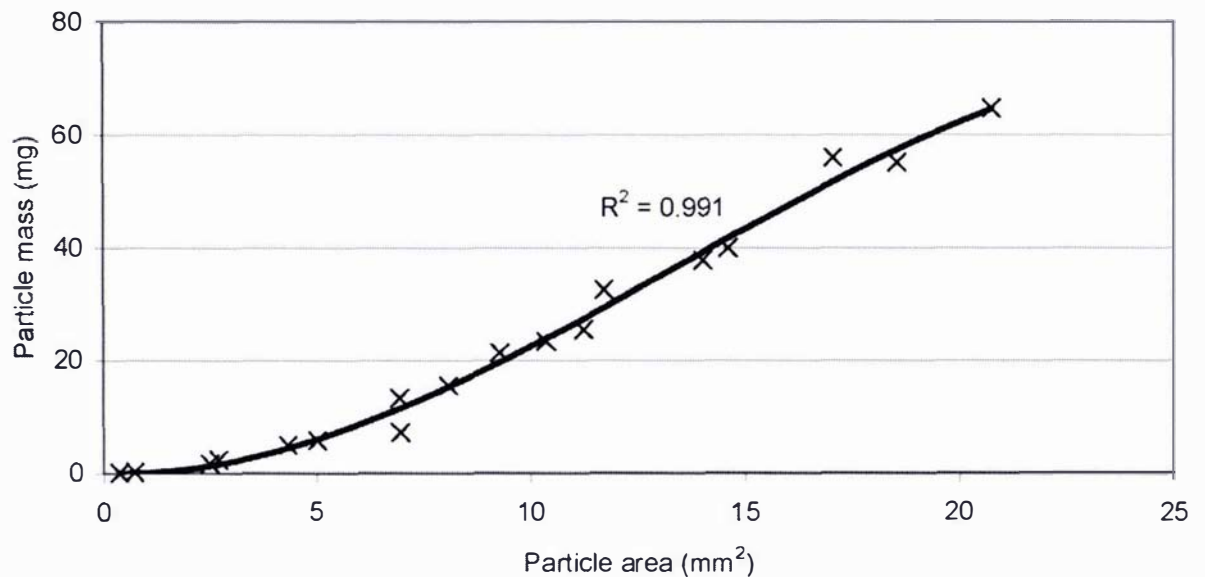


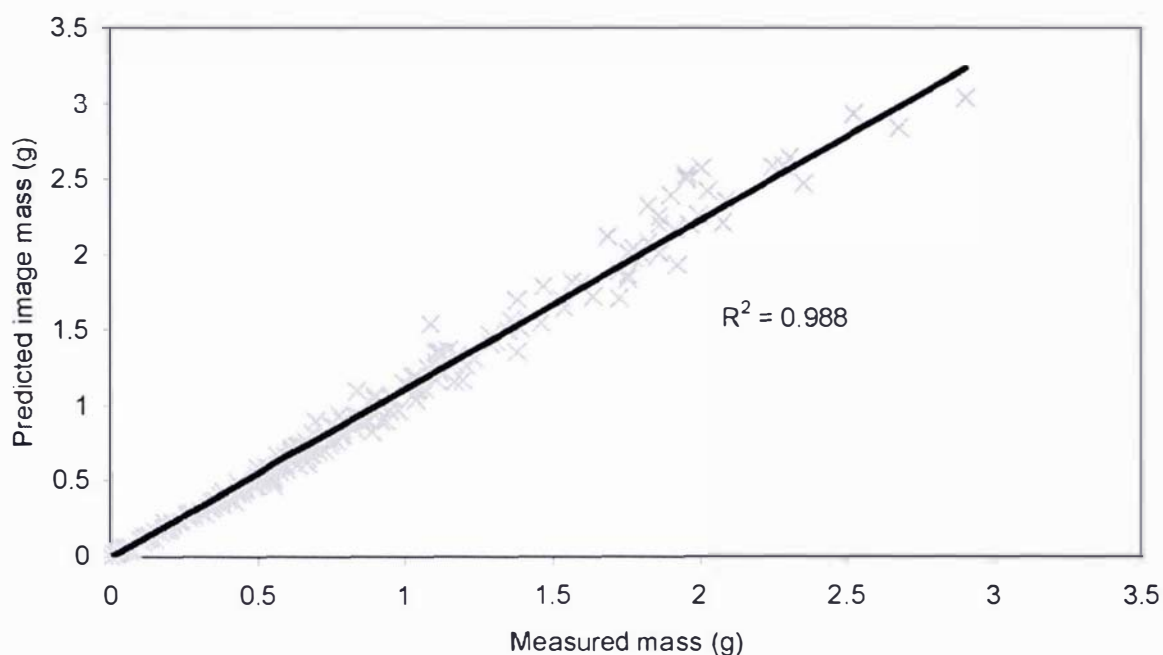
Figure 4.4. 2<sup>nd</sup> order polynomial regression analysis of particle area (mm<sup>2</sup>) and particle mass (mg) of urea particles contained in sieve apertures between 0.4 and 4.0 mm.

### Test 3

A total of 330 tray images were captured from three transverse and five longitudinal rows trays laid out during a fertiliser spreader test (Figure 4.3). Each captured image was processed using the method described. The total mass of particles collected on each tray was estimated using the calibration equation developed from calibration testing [1]. Over all 330 trays there was a significantly high relationship ( $R^2 = 0.988$ ) between measured image mass using a balance and image mass calculated using the particle area calibration equation [1] to determine total particle mass from captured images (Figure 4.5). The calculated standard error for the data set was 0.75 g per tray.

The level of error in predicting total particle mass increases as measured mass increases (Figure 4.5). The data set was split into three groups, measured masses between 0.0 and 1.0 g ( $G_1$ ), masses between 1.0 and 2.0 g ( $G_2$ ) and masses between 2.0 and 3.0 g ( $G_3$ ). Results indicated that error level significantly increased ( $p < 0.001$ ) increased as particle mass contained on a collection tray increased. Group  $G_1$  had an expected error level of 5.8 % compared to group  $G_2$  and  $G_3$  with expected error levels of 12.4 and 12.6 % respectively. Longitudinal transects  $L_1 - L_5$  (Figure 4.3) were used to determine whether expected error was related to distance from the spreader. It was found that expected error for transect  $L_1$  and  $L_5$  was 2.0 and 0.4 % respectively compared to transect  $L_2$ ,  $L_3$  and  $L_4$  which had expected errors of 4.0, 9.0 and 13.2 % respectively.

Although there was a decline in particle mass with relation to distance from the spreader, there was also an increase in the proportion of particles retained in sieve apertures below 1.0 mm. Particles within this range had a lower identification rate than particles retained in sieve apertures greater than 1.0 mm using the described methodology (Table 4.4).



**Figure 4.5. Regression analysis of predicted total tray mass calculated from total particle area (g) and actual measured total particle mass (g) of urea contained in a 500 x 500 mm fertiliser collection tray.**

Using the described method it was possible to calculate physical characteristics of individual particles and therefore perform particle size and uniformity calculations. Calibration results were used to determine physical characteristics of individual particles contained within each sieve aperture. Physical particle characteristics (particle area, major and minor axis) were found to increase as sieve aperture size increased (Table 4.6). Major axis was not as good at predicting which sieve particles were contained in because of the elongation factor of some urea particles. The minor axis of individual particles was found to be the most representative of sieve size; however, particles were found to be present with minor axis measurements greater than the sieve aperture they were contained in. This was more prevalent in sieve apertures of 1.0, 2.0 and 2.8 mm.

**Table 4.6. Average physical characteristics of particles contained in sieve apertures between 1.0 and 4.0 mm<sup>2</sup> extracted from image analysis.**

Sieve Aperture Size	1	2	2.8	3.35	4
Particle area (mm <sup>2</sup> )	7.40	10.37	12.20	13.87	15.97
Major Axis (mm)	2.83	3.94	4.62	5.27	6.05
Minor axis (mm)	1.73	2.45	2.91	3.30	3.84

Initially particle attributes obtained from the image analysis were used to perform a “computer sieve”. This analysis was based on grouping particles with minor axis less than that of manual sieve aperture sizes (Table 4.6). Results from using computer sieving to group data into specified sieve sizes were compared to manually sieved samples from field trials. An expected error of 7.3% was calculated for predicting the percentage of particles contained within in each sieve aperture on a single tray using the image processing method. A revised method using physical characteristics calculated from calibration results (Table 4.6) to perform a computer sieve of the field data provided a more accurate representation of particle size distribution. Average error over all field tests was 6.0% using particle characteristic constraints. However, the difference in the two means (1.3%) was not significant at the 0.05 level when using the t-test statistic ( $t = +0.369, df = 8$ ).

The data from each transverse test was used to calculate the post spreading SGN and UI, this was compared to the results calculated using physical sieve analysis. Table 4.7 shows calculated SGN and UI values in all transverse tests using both the manual and image sieve analysis methods. In all tests the calculated SGN increased whilst the UI decreased. A higher SGN value indicates a larger mean particle size whilst a lower UI indicates larger variation within particle size. The calculated SGN and UI were very consistent between tested transects, 317 – 319 and 321 - 324 for SGN, and 46 – 47 and 41 – 42 for UI using both the manual and image analysis methods respectively. This indicated that using the image processing method can consistently measure SGN and UI across an entire sample.

**Table 4.7. Comparison of Size Guide Number (SGN) and Uniformity Index (UI) calculated from both mechanical sieving and computer sieving using image analysis.**

		Physical Analysis	Image Analysis
t <sub>1</sub>	SGN	319	324
	UI	46	42
t <sub>2</sub>	SGN	319	321
	UI	46	41
t <sub>3</sub>	SGN	317	323
	UI	47	41

Data from each transect (Figure 4.3) was used to measure the overall spread pattern from the spreading vehicle using both the manual and image analysis methods. For transverse tests the error was 13.4, 8.9 and 9.3% for transects T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub> respectively whilst for the longitudinal tests L<sub>1</sub>, L<sub>2</sub>, L<sub>3</sub>, L<sub>4</sub> and L<sub>5</sub> measured error in image mass was 0.4, 13.2, 9.0, 4.4 and 2.0% respectively. Transverse error was found to be significantly higher (19.7%) on trays within  $\pm 4$  m of the spreading vehicle, outside this distance error in predicting tray mass from images was only 5.3%. Transects L<sub>1</sub> and L<sub>5</sub> had the lowest prediction error for all longitudinal transects, these transects were at the extremities of the distribution pattern and were found to have a larger mean particle size than transects near the centre of the distribution pattern.

Spread pattern information using both the manual and image analysis methods was used to calculate the coefficient of variation (CV) at bout widths between 0 and 40 m for all transverse transects. The average error in transverse CV at varying bout widths was 6.3, 1.9 and 3.2% for transects T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub> respectively. Transects T<sub>2</sub> and T<sub>3</sub> predicted the same bout width using both the manual and image processing methods when CV was less than 15%, these were 8 and 10 m respectively.

#### **4.5. DISCUSSION**

Results from Test 1 showed that particles below 1 mm had lower identification rates than larger particles. The main reason for low particle identification was particles that were identified as noise within the image and therefore removed during the filtering process. Particles post spreading ranged between 0.03 and 9.26 mm<sup>2</sup>. A captured tray image contained approximately 5 million pixels, each image was 500 x 500 mm, therefore a small 1 mm<sup>2</sup> fertiliser particle was approximately 20 pixels whilst a larger 4 mm<sup>2</sup> particle was approximately 80 pixels. Often particles less than 10 pixels were removed as they could not be differentiated from the background clearly due to similar pixel intensity values. This was seen as one of the major

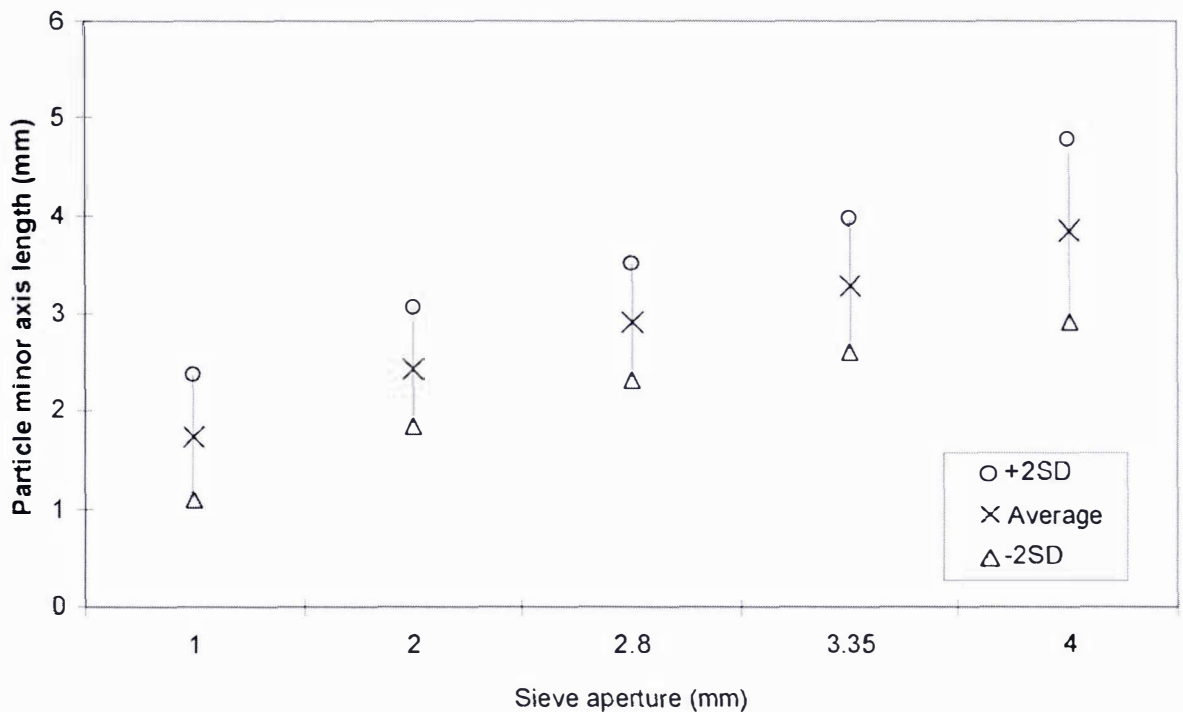
limitations of the system, especially near the centre of the distribution pattern where the number of particles of less than  $1 \text{ mm}^2$  was significantly greater than at the extremities of the distribution pattern.

There was found to be a very good relationship between 2D particle area and particle mass ( $R^2 = 0.991$ ) when performing calibrations in a controlled image capture environment, however expected error ( $\pm 4.1\%$ ) was higher than that expressed by Banta et al (2003) who had an expected error of  $\pm 2\%$  when predicting mass from 2D images of lime particles. The error increased to  $\pm 7.5\%$  when using images captured in the field to predict total mass on a single tray; almost double that obtained from calibration images. The regression coefficient for field images was still very strong ( $R^2 = 0.988$ ). The increase in error level was attributed to the large range in particle sizes that needed to be identified in individual field images. Calibration images were split into different sized sieve apertures making the thresholding process a lot easier to define. However, this was not possible in field images. Smaller particles were found to have lower intensity values than larger particles, therefore, when the intensity level was outside that defined from auto-thresholding, particles were removed. Another source of error in captured field images was found to be the increase in mass prediction error as collected material mass increased. It was found that trays around the centre of the distribution pattern, where more fertiliser was distributed, had larger level error levels when predicting tray mass than trays towards the extremities of the distribution pattern. The major reason for this was found to be the proportion of small broken particles that were removed during the filtering process either as background noise or incorrect shape match. This could potentially create large errors in the calculation of transverse CV when high application rates are used during testing.

One of the major benefits from using image processing over manual processing methods is having the ability to identify specific attributes of individual particles (Banta et al., 2003; Cruvinel et al., 1999; Nazar et al., 1996). The major parameters extracted in this study were 2D particle area, major and minor axis. 2D particle area was essential in calculating particle mass whilst major and minor axis was used to perform a "computer sieve" on tray samples. When data from the "computer sieve" was compared to manually sieved data from each sample, there was found to be a relatively large discrepancy in measured results. The minor axis of each particle was used to compare manually sieved data to computer sieve data. Figure 4.6 shows data obtained from calibration results where the minor axis of particles contained in each sieve size was measured. This shows, although average minor axis length was increasing there was a significant overlap within each

sieve size. This contributed to the error obtained when trying to computer sieve the dataset.

Although there was variation in predicted mass in each sieve aperture, this did not significantly change the calculated results for SGN and UI. Table 4.7 showed that SGN was over predicted by on average by 4.7 units and uniformity index was on average under predicted by 5.0 units between using manual and image sieve analysis. Even spreading of fertiliser should occur when SGN is between 250 and 350 and UI is between 20 and 60 (Table 4.1). Using both the manual and image analysis methods SGN and UI were found to be within this range. Previous work by the authors found that over 20 samples taken from the same bulk sample of urea pre-spreading SGN and UI ranged between 272 to 393 and 49 to 61 respectively. Post-spreading analysis indicated that SGN was within this range; however, UI was less than the range specified pre-spreading indicating that particle uniformity had decreased between pre and post-spreading, indicating particle breakage.



**Figure 4.6. Distribution of minor axis lengths for individual particles contained within sieve apertures between 1.0 and 4.0 mm.**

The prediction of bout width under a certain level of variation is critical in order for fertiliser application to be accurate. Test results indicated that two of the three transverse tests measured using both the manual and image analysis methods predicted the same bout width at a CV of less than 15%. Over all tests, mass was

predicted with sufficient accuracy when further than  $\pm 5$  m from the spreading vehicle, however, significant error in the prediction of tray mass was evident for trays within  $\pm 5$  m. Trays around the centre of the distribution have the greatest influence on the calculation of CV, therefore, are required to be accurately predicted in order for the CV calculation to be accurate and repeatable.

Overall, the identification percentage obtained using this method was comparable with other methods practiced throughout the world when particle analysis was performed prior to spreading, however, post spreading results were significantly less accurate especially trays that were within  $\pm 5$  m of the spreader. Figure 4.7a shows a tray sample within  $\pm 5$  m and Figure 4.7b shows a tray outside  $\pm 5$  m. On average, 39.5% of particles within trays inside  $\pm 5$  m of the spreading vehicle were contained within a sieve aperture of less than  $1\text{ mm}^2$ , this compared to 5% within  $\pm 5$  to 8 m and 0% within  $\pm 8$  to 12 m of the spreading vehicle. The high percentage of pan particles was highly correlated to high error levels when using the image processing method on field test data. Yet, in two of the three transverse transects measured using both the manual and image processing methods the same bout width was calculated. However, further testing of the image processing method would be required to verify this accuracy.

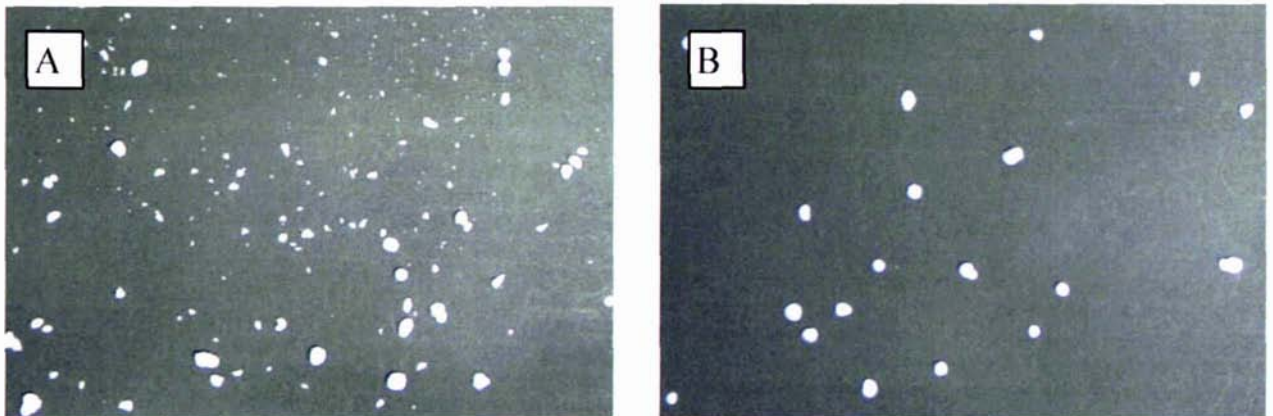


Figure 4.7. Raw images capture from a tray inside  $\bullet 4$  m of the spreading vehicle (a) and outside  $\bullet 4$  m from the spreading vehicle (b).

#### 4.6. CONCLUSION

The major advantages of using the image processing method over the standard tray measurement system include the reduction of laboratory work required in order to obtain particle distribution information from a spreader test. Using the image processing method, all required information was calculated using the designed

LabView algorithm (National Instruments, 2004) there was no requirement for manual weighing or sieving of collected tray material apart for comparative measures, which, in turn, limited the physical resources required for testing. Another major advantage of the designed system was the data that could be extracted. As well as performing simple weighing and sieving tasks the method can also be used to extract shape information to identify particle breakage factors calculated from pre spreading measurements as well as used on mixed fertilisers to measure chemical distribution results. A potential disadvantage of the system is the large number of mass conversion algorithms that would be required to satisfy the different types of fertilisers used during the testing process. The major results from the research are presented in the following.

- Particle identification results prior to spreading were high with identification rates of  $> 90\%$  when particles were contained in sieve apertures of greater than  $1 \text{ mm}^2$ .
- Regression analysis identified a significantly positive relationship ( $R^2 = 0.991$ ) between tray particle mass and Projected 2D tray particle area on calibration images. The developed equation was used to predict total particle mass on images captured in the field. A strong relationship ( $R^2 = 0.988$ ) between measured and predicted particle mass was obtained.
- When fertiliser mass contained within individual trays was high ( $> 1.5 \text{ g}$ ) error in predicted mass using the image processing method increased significantly. Typically, mass was under-predicted due to small particles being removed during the image filtering process. The majority of trays with masses greater than  $1.5 \text{ g}$  were found to be within  $\pm 4 \text{ m}$  of the spreading vehicle,  $39.5\%$  of particles contained in these trays were held within a sieve aperture of less than  $1 \text{ mm}^2$ .
- The high error level in mass prediction when a large proportion of particles was less than  $1 \text{ mm}^2$  indicated that improvements in the method are required; however, the method was able to accurately predict SGN and UI for both pre- and post-spreading samples.
- Field test particle analysis results indicated that post-spreading particle size was reduced from pre-spreading particle size signifying mechanical breakage of individual particles by the spreading vehicle.
- The method proved that individual particle characteristics can be easily and accurately obtained if particle size of greater than  $1 \text{ mm}^2$  could be achieved. The method could be used in future research to better understand the ballistic properties of individual fertiliser particles from a

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spinning disc applicator and used to adjust and verify application models.

In conclusion, the developed image processing method had its limitations in field conditions especially at high application rates where large numbers of particles are contained in a single tray. However, this method used in conjunction with a tray weighing system would provide added information that could be used to further understand the dynamic behaviour of fertiliser particles spread from spinning disc applicators.

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## CHAPTER 5

### ESTIMATION OF THE INFIELD VARIATION OF FERTILISER APPLICATION

#### *Paper Reference*<sup>9</sup>

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Lawrence, H. G., I. J. Yule. (2007). Estimation of the infield variation of fertiliser application. New Zealand Journal of Agricultural Research 50(1): 25–32. Received 13 April 2006; accepted 20 December 2006.

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*Abstract.* Variation in field application from a centrifugal fertiliser spreader has, in the past, been difficult to assess due to the intensive field testing required. However, with the application of current technologies such as Global Positioning Systems and Geographic Information Systems, the assessment of field application variation is now possible. The aim of this research was to develop a method to assess field application variation using basic transverse spread pattern test and vehicle tracking data. The information was used to measure and compare the effect of spread pattern, driving accuracy, driving method and paddock shape. Two differently shaped paddocks were used for analysis, one rectangular, the other triangular. A simple analysis method was initially used to calculate which areas of the paddock received nil, single or double application. An advanced assessment method was also developed to measure application variation within the paddock and to calculate field application variation. Transverse spread pattern data was averaged at 2 m increments and linked to GPS tracking data from the spreading vehicle within the GIS environment of ArcGIS 9.1©. The data set was then analysed and a field application map produced. The field coefficient of variation (CV) was then calculated from the application map. Three simulations of perfect driving width and perfect application pattern were also conducted as a means of comparison to the actual field data. Simple analysis results showed, in both paddocks, the area receiving the correct application rate was between 70 and 80%, with 5 – 15% of the area receiving nil application. Using the advanced analysis method, the calculated field CV was 32.9% and 43.0% for the triangular and rectangular paddocks respectively. However, when

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<sup>9</sup> This chapter contains some changes to the published paper resulting from examiner emendations.

*simulated “perfect driving” tracking data was used, the average field CV was reduced to 24.8% and 23.5% respectively. When both perfect driving and a perfect spread pattern were used field application variation could be reduced to less than 20% for either shaped paddock. The results concluded that there is far greater variation in field application of fertiliser than that measured from a single transverse test, with the single biggest gain in calculated field CV being from driver accuracy and driving method.*

**Keywords.** *Fertiliser spreading; transverse testing; GPS tracking; GIS interpolation; precision agriculture.*

## **5.1. INTRODUCTION**

Traditionally, spreader performance has been measured using a single transverse spread pattern test. The Spreadmark© quality assurance program (NZFQC, 2006) specifies a level of variation for this test of less than 15% for nitrogenous fertilisers and 25% for non-nitrogenous fertilisers in order to gain compliance. However, there are many variables that effect the distribution of fertiliser. These variables include product variation, product transport and storage conditions, spreading equipment and land configuration and topography. Many of these variables have been researched and evaluated in detail. For example, within-product variation is measured by a uniformity index (UI). Higher UI values represent fertilisers where particle sizes are uniform e.g. Urea, Lower UI results are found with fertilisers with a wider range of particle sizes (NZFQC, 2006). Variations in products can be defined by the size guide number (SGN) which is the mean particle size, measured in millimetres. Both UI and SGN can be used to describe fertiliser variability and are often used to describe “spreadability” and “compatibility” of different products. The movement of fertiliser from bulk store to farm can often significantly affect the fertiliser’s characteristics, therefore increasing the variability during application. It is important that fertiliser waiting to be spread is completely free from any contaminants, large lumps, foreign objects or debris and is sufficiently dry and in a condition where it will flow freely (CAANZ, 2005). Centrifugal spreading equipment and performance have, for some time, been considered to have the greatest influence on fertiliser application variability. Olieslagers et al. (1996) described the requirements to model fertiliser distribution as the interaction of spreader settings, particle characteristics and the environment. Their model identifies the key spreader functions having the greatest impact on spreader pattern as being disc, vane and orifice. Commonly, the effect of spreader settings on transverse distribution from a

spreader is well documented; however, the effect of driving accuracy, the variability on undulating terrain and land configuration is not. The inconsistency of these factors can significantly increase the application variability of fertiliser on the land.

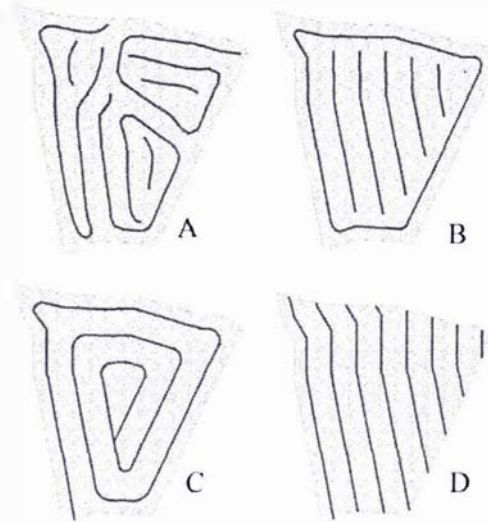
There has been a large amount of work on modelling fertiliser application from centrifugal spreaders and the effect of using GPS guidance to improve field performance of various agricultural applications; however, these two fields of research have rarely been combined to provide an overall measurement of field performance. Parish & Bergeron (1991) stated that variation in spreading would probably double under field conditions when compared to a controlled transverse test.

Initiatives by the New Zealand fertiliser industry have aimed to minimise the variability in fertiliser application, these initiatives include the Spreadmark and Fertmark quality assurance programs and the introduction of both GPS tracking and guidance systems to spreading vehicles. However, this information collected independently does not give an overall indication of field application variability. Therefore, the aim of this research was to develop a method to assess in-field performance of a fertiliser spreader using a combination of field tracking and spread pattern test data.

## **5.2. MATERIALS AND METHODS**

Two series of tracking data and corresponding spread pattern test results were obtained to use in the analysis of field performance, each data series had two individual paddocks. The spread pattern data used in this test was obtained from a Spreadmark quality assurance test: although the ACCU-Spread test was shown to be superior in chapters 2 & 3 for defining bout width the Spreadmark test is specific to the New Zealand environment and was used here. Once bout width is defined further modelling of spread patterns over a field will yield identical results for a given bout width, however obtained. The two spreaders used were a Bredal centrifugal twin disc spreader and a Transpread centrifugal twin disc spreader. The spreaders were certified to spread at a 26 m (app. rate = 150 kg ha<sup>-1</sup>) and 16 m (app. rate = 100 kg ha<sup>-1</sup>) swath width respectively. Both sets of tracking data were collected using GPS systems that had expected accuracies of less than 0.1 m. Initially the tracking data had to be converted into a format that could be handled in ArcGIS 9.1® (ESRI, 2005). Each file was converted using a program written in MS Visual Studio.NET® with information regarding spreading vehicle location, application rate and swath width. Once in the GIS platform the

converted files were transformed to a series of points, these points were then converted to polylines, each polyline was geotagged with an application rate and swath width which showed where the spreader had applied fertiliser in the field. Two paddocks for each spreader were used for analysis, in all situations the targeted application rate was  $80 \text{ kg ha}^{-1}$  of urea (46%N). In addition to the actual tracking and spread pattern data collected from the spreading vehicle, three tracking simulations were created in order to compare perfect spreading scenarios to “real time” variation. The driving methods evaluated were: actual data (Figure 5.1A), up and down (Figure 5.1B), round and round (Figure 5.1C) and perfectly straight (Figure 5.1D). Two methods were developed in the GIS platform to analyse both the tracking and spread pattern data; these are explained in further detail below.



**Figure 5.1. Spreader driving methods evaluated; (a) actual data; (b) up and down; (c) round and round; and (d) perfectly straight using a Bredal spreader with a 26 m bout width.**



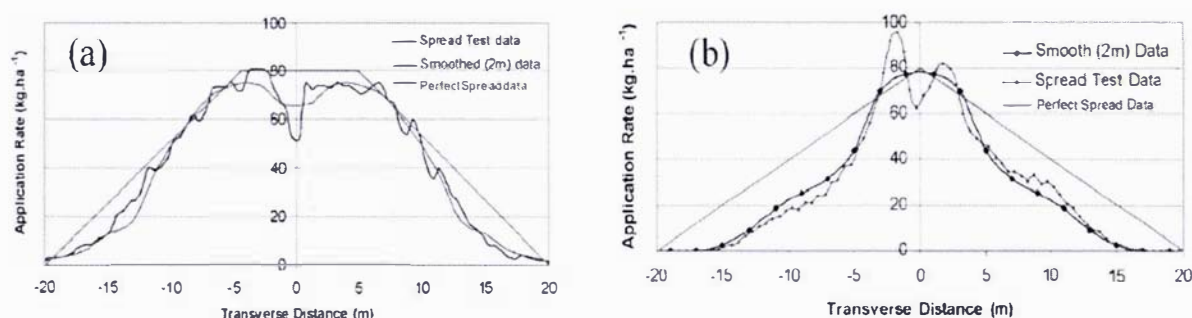
**Figure 5.2. Output from Basic spreader interpolation data showing areas receiving single and double application rates using a Bredal spreader with a 26 m bout width.**

### Method 1 – Basic

The Basic analysis method used tracking information collected when the spreading vehicle is applying fertiliser. A buffer, at the certified bout width was then drawn around each of the track lines. Each of the buffers from each track line were then joined and intersected. A count was performed on each intersected polygon; this count determined whether a particular area received a nil, single, double or triple application of fertiliser (Figure 5.2).

### Method 2 – Advanced

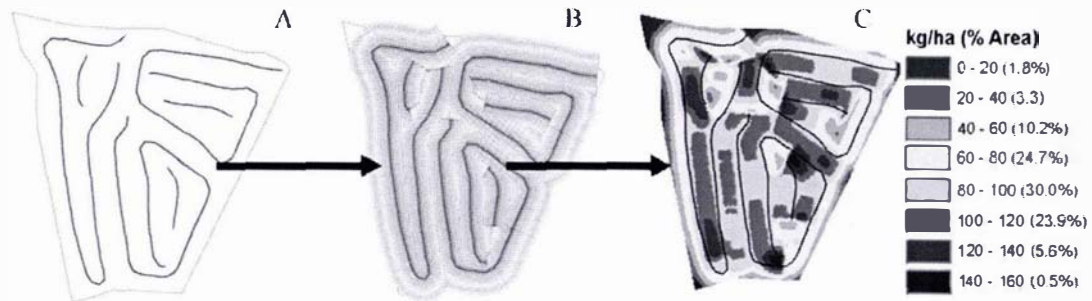
The advanced method used a combination of tracking and spread pattern data. Individual buffers at two metre intervals were placed adjacent to each of the track lines and geotagged with an average application rate ( $\text{kg ha}^{-1}$ ) for each interval using ArcGIS 9.1 (ESRI, 2005). The average application rate was derived from the spreaders Spreadmark© certified spread pattern test where measured CV is less than 15% for the specified track spacing. The raw data from the spread pattern test was averaged at two metre intervals for the entire transverse distribution to give an average application rate for each of the buffer ranges. Two spread patterns were used, a 26 m swath flattop spread pattern from a Bredal spreader (Figure 5.3a) and a 16 m swath triangular shaped pattern from a Transpread spreader (Figure 5.3b).



**Figure 5.3. Actual, smoothed, and perfect spread pattern test data for Urea (46% N) for a (A) 26 m swath flattop spreader (Bredal); and (B) 16 m swath triangular spreader (Transpread).**

An intersection was performed on the overlapping buffers. This allowed areas of the spread pattern that overlapped to be added together to obtain a specific application rate for the particular site. A series of sample points at 1 m x 1 m intervals was established for each paddock; the point grid was then used to sample the summarised buffered layer for actual application rate. Using geostatistical analysis, an application map was created from the sample points. Figure 5.4 shows the process from tracking data through to the creation of the

application map. The application map was used to generate application statistics and to calculate the field variation expressed as the CV.



**Figure 5.4.** Process used to create a field fertiliser application maps using a Bredal spreader with a 26 m bout width; A. raw track data; B. adjacent buffers from track lines; C. kriged application map.

The economic loss from poor spreading was calculated using information sampled from the application map. An average nitrogen to pasture response function derived from Ball & Field (1982) was calculated for each scenario based on application statistics. The difference in pasture yield gain between the expected pasture response (based on 80 kg ha<sup>-1</sup> Urea) and the actual response under the different scenarios was used to calculate the expected production gain. The production gain was valued for New Zealand dairy pasture at 20c kgDM<sup>-1</sup> (Horrell et al., 1999). The economic loss for each scenario was compared to its relevant field CV to identify a relationship between the two.

### 5.3. RESULTS AND DISCUSSION

#### *Basic Method Results*

The basic field analysis method developed in this research allowed areas receiving correct, under- or over-application to be identified. Figure 5.5 shows the actual driving paths of two spreading vehicles on different paddocks. It is evident that paddock A and paddock B had greater overlap than paddocks C and D respectively. This may have been induced by the wider 26 m swath width used in paddocks A & B compared to the 16 m swath width used in Paddocks C & D. However, GPS guidance was used in all four situations which should have helped reduce this overlap error. Paddock shape and topography appeared to have the greatest impact on overlap, especially on paddock A which was of irregular shape, therefore, a conventional

driving pattern (e.g. up & down, round & round) was not performed. Paddock B clearly shows a large edge effect where the driver has failed to spread to the paddock's extent, meaning this area would have received a lower than optimal application of urea affecting overall paddock response.

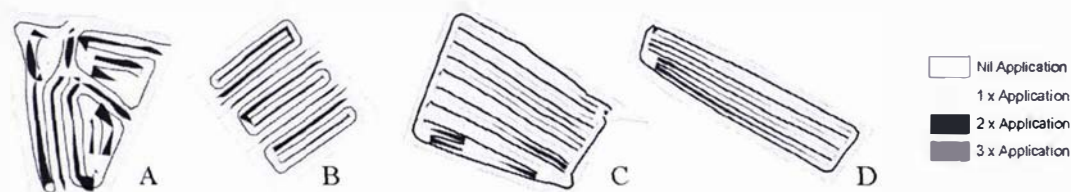


Figure 5.5. Basic application interpolation method results for tested paddocks A-D

Table 5.1 summarises the statistical data from Figure 5.5. Paddock C and D at the narrower 16 m swath clearly achieved a single application more often than the 26 m swath spreader used on paddocks A and B (88% & 84% and 77% & 73% respectively). Paddocks C and D also had lower double application rates (4 – 6%) than paddocks A & B (11 – 17%). In all situations, regardless of paddock shape or swath width, the nil or low application area can be under 10% of total area; in the one case where low application area exceeded 10% (Paddock B – 16%) significant border effects were identified.

Table 5.1. Percentage of total area receiving different levels of fertiliser application on four individual paddocks using a 26 m and 16 m swath spreader.

	26 m Swath Width		16 m Swath Width	
	Paddock A	Paddock B	Paddock C	Paddock D
Low Application area ( $\leq 52$ kg ha <sup>-1</sup> )	7%	16%	8%	10%
1x Application (52-82 kg ha <sup>-1</sup> )	77%	73%	88%	84%
2x Application (104-164 kg ha <sup>-1</sup> )	17%	11%	4%	6%
3x Application (156-246 kg ha <sup>-1</sup> )	0%	0%	0%	0%

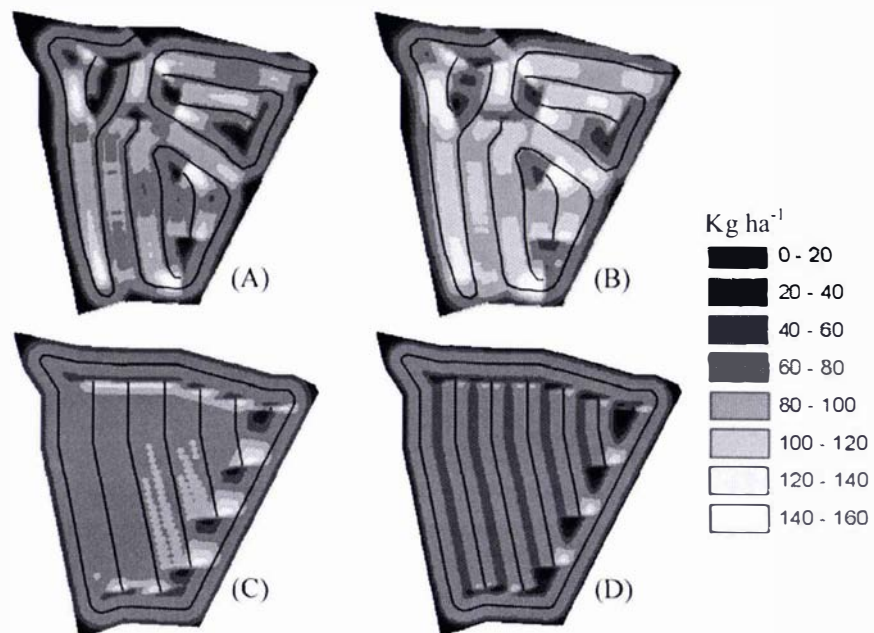
*NB. Paddock A = Triangular shape, Paddocks B, C and D = Rectangular shape*

### Advanced Method Results

Figure 5.6 shows four of the eight simulations performed on Paddock A. The spatial variability of the four application maps are attributed to the use of both actual and theoretical tracking and spread pattern data. Figure 5.6a shows the actual collected data (actual tracking, actual spread pattern) where overall coefficient of variability (CV) was 32.9%. The target application rate of 80 kg ha<sup>-1</sup> of urea (46% N) was achieved on 24%

( $\pm 5\text{kg}\cdot\text{ha}^{-1}$ ) of the total paddock area, assuming perfect longitudinal spread pattern stability. Figure 5.6b shows using the same vehicle tracking data at the theoretical optimum spread pattern the overall CV was reduced to 29.6%. However, the target application rate was only achieved on 22% ( $\pm 5\text{ kg ha}^{-1}$ ) of the total paddock area, this was largely due to the areas where the swath width was greater than 26 m.

Overall field CV was improved when the actual spread pattern was used but a theoretical optimum for up and down vehicle tracking were used (Figure 5.6c). The overall CV was reduced to 24.4% and the target application rate was achieved on 39% of the total area. When both a theoretical spread pattern and up and down vehicle track was used overall field CV could be reduced to less than 20% with the target application rate being achieved on 74% of the area (Figure 5.6c).



**Figure 5.6. Spatial variation in Paddock A using a Bredal spreader with a 26 m bout width assuming no longitudinal variation when using (A) actual tracking data and actual spread pattern; (B) actual tracking data and a perfect spread pattern; (C) simulated up and down tracking data and actual spread pattern; and (D) simulated up and down tracking data and perfect spread pattern.**

In total, 32 simulations were performed over four paddocks, the field CV ranging from 8.5% to 43% when using a perfectly straight vehicle track (Figure 5.2d) combined with a perfect spread pattern and the

actual collected data (Figure 5.2a) combined with actual spread pattern information from Paddocks C (Figure 5.54) and A (Figure 5.5c) respectively.

**Table 5.2. The effect on field CV of using an actual and perfect spread pattern over four sampled paddocks.**

Spread Pattern	Pad A	Pad B	Pad C	Pad D	Avg CV	SD
Actual	32.9%	43.0%	25.6%	31.0%	33.1%	7.3%
Perfect	29.6%	39.0%	20.8%	26.6%	29.0%	7.6%

*NB. Paddock A = Triangular shape, Paddocks B, C and D = Rectangular shape*

Table 5.2 shows the range in calculated field CVs over four paddocks using the actual collected tracking data and an actual and perfect spread pattern. The average field CV when using actual spread and vehicle tracking data was 33.1%. This was reduced to 29.0% when using a theoretical optimum spread pattern. However, these means were not significantly different ( $P > 0.05$ ), indicating that on these sampled paddocks the difference between using an actual spread pattern with a transverse CV of 15% and a perfect spread pattern with a transverse CV of 0% did not largely reduce field variation (< 5%).

**Table 5.3. The effect of driving method on field CV when using an actual tested spread pattern and simulated driving pattern on four sampled paddocks.**

Driving Method	Spread Pattern	Pad A	Pad B	Pad C	Pad D	Avg CV	SD
Up & Down	Actual	24.4%	24.4%	23.9%	31.0%	25.9%	3.4%
R & R	Actual	29.0%	26.3%	24.5%	25.8%	26.4%	1.9%
Straight	Actual	21.1%	19.9%	14.8%	29.9%	21.4%	6.3%

*NB. Paddock A = Triangular shape, Paddocks B, C and D = Rectangular shape*

**Table 5.4. The effect of driving method on field CV when using a perfect spread pattern and simulated driving pattern on four sampled paddocks.**

Driving Method	Spread Pattern	Pad A	Pad B	Pad C	Pad D	Avg CV	SD
Up & Down	Perfect	18.3%	18.7%	19.6%	15.0%	17.9%	2.0%
R & R	Perfect	21.4%	17.2%	19.2%	19.9%	19.4%	1.7%
Straight	Perfect	14.1%	11.6%	8.5%	16.1%	12.6%	3.3%

*NB. Paddock A = Triangular shape, Paddocks B, C and D = Rectangular shape*

Perfect simulations were devised to analyse the effect of driving method on field CV. The best driving method when using both the actual spread pattern (Table 5.3) and perfect spread pattern (Table 5.4) was the simulated perfect straight driving method, however, it was deemed unrealistic for a truck to perform this way (Figure 5.1d). The simulated up and down method resulted in a slightly better average field CV than the

simulated round and round method when using an actual spread pattern (25.9% and 26.4% respectively) and perfect spread pattern (17.9% and 19.4% respectively). A field CV of less than 20% could be obtained when using both a theoretical optimum for driving and optimum spread pattern. Remaining application variation was most probably due to paddock shape and size. In order to have nil field variation a controlled traffic situation with field headlands would be required (impractical on a general farm layout).

### ***Economic Analysis Results***

Figure 5.7 shows the economic loss in production that a pastoral farmer could expect at varying levels of field variation. The third order polynomial relationship between field variation (%) and economic loss (Figure 5.7) showed a strong correlation ( $R^2 = 0.95$ ). Horrell et al. (1999) deemed \$5.00 ha<sup>-1</sup> as being a significant loss to a New Zealand pastoral farmer. This being true, a field CV of less than 30.1% would need to be obtained in order to prevent this loss. When using actual tracking and spread pattern data, economic losses greater than \$10 per hectare were obtained, double the level deemed a significant loss. When using actual tracking and spread pattern data on all four paddocks, only paddock C (Figure 5.5c) achieved a field CV of less than 30.1%. All field CV's were less than 30.1% when using perfect driving scenarios.

**Table 5.5. Average economic loss from three spreader tracking scenarios using an actual and perfect spread pattern on a pasture based grazing system.**

Driving	Spread Pattern	Economic Loss (\$ ha <sup>-1</sup> )
Actual	Actual	\$7.29
	Perfect	\$6.35
Up & Down	Actual	\$2.93
	Perfect	\$1.45
Round & Round	Actual	\$3.05
	Perfect	\$1.05

\* Pasture based on a value of \$0.20 kg DM

Table 5.5 shows the average economic loss for each driving method and spread pattern over the four paddocks. It is evident that there is a greater reduction in economic loss when driving accuracy is improved (up & down, round & round simulations) compared to the difference between using an actual and a perfect spread pattern. The average economic loss was not significant (<\$5.00 ha<sup>-1</sup>) when using either the perfect up and down or round and round driving methods for either the actual or perfect spread pattern. However, the loss was significant (>\$5.00 ha<sup>-1</sup>) when using the actual driving pattern. Horrell et al. (1999) deemed a CV of

40% as creating a significant economic loss to a dairy farmer; however, this work included only the effect of transverse spread variation and did not take into account paddock shape or driving accuracy. Although longitudinal accuracy was not considered in this work results still indicated that a significant economic loss was achieved at a field CV of greater than 30.1% when including these factors (Figure 5.7).

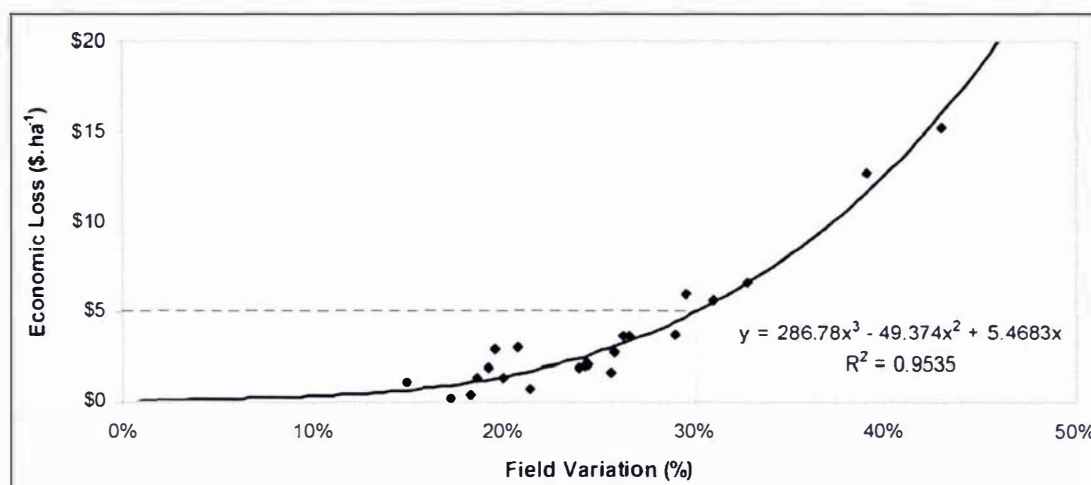


Figure 5.7. Field application variation (%) versus economic loss per hectare (\$ ha<sup>-1</sup>) calculated from the effect of uneven spreading on production response of New Zealand dairy pasture (kg DM kg N<sup>-1</sup>).

#### 5.4. CONCLUSION

Results obtained from this research include the evaluation of a basic and advanced fertiliser application modelling tool and their ability to calculate field variation. Created scenarios allowed the analysis of driving method, driving accuracy, paddock shape and spreader pattern effect to be analysed. Economic loss calculations allowed each scenario to be quantified in terms of significance to a New Zealand pastoral farmer.

There was far greater variation in field CV than that measured from a single transverse test. Both tested spreaders had transverse spread variation of less than 15%, however, the average field CV was calculated to be 33.1%, indicating that 18.1% of the variation was due to either driving accuracy, driving method or paddock shape. The field CV could be reduced to less than 30% in all scenarios when using either an up and down or round and round driving method with perfect pass to pass accuracy.

A significant economic loss from nitrogen application was found to occur when field CV was greater than 30%; in all but one paddock analysed using field collected data the field CV was greater than this level.

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The field CV in all scenarios could be reduced to less than 30% when using perfect driving, but, this could not be achieved when using a perfect spread pattern on the actual collected tracking data.

In conclusion, the results obtained from this analysis showed that there needs to be a far greater analysis of the entire fertiliser application system, not just the transverse variation, and the method and results presented indicate a way forward in estimating actual field application rates. The repetitive use of this method in individual paddocks over different fertilisers applied could provide much more accurate spatial information of nutrient supply at the sub paddock level and be used to calculate production gains and efficiency from fertiliser applications. It would also be a useful technology when considering nutrient budgets.

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## CHAPTER 6

# A GIS METHODOLOGY TO CALCULATE THE IN-FIELD DISPERSION OF FERTILISER FROM A SPINNING DISC SPREADER

### *Paper Reference*<sup>10</sup>

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Lawrence, H. G., I. J. Yule. (2007). A GIS methodology to calculate the in-field dispersion of fertiliser from a spinning disc spreader. Transactions of the American Society of Agricultural and Biological Engineers, 50(2): 379–387. Received 25 July 2006; accepted 11 December 2006

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**Abstract.** A model was developed within a GIS environment which used the transverse spread pattern and GPS driving track during spreading to map actual fertiliser application at any point in a paddock. The spreading vehicle required a GPS of sufficient accuracy in order to provide proof of placement and guidance assistance to the driver. The method was used to assess the effect of field size and shape on actual application rate and application variation. At a target application rate of 80 kg ha<sup>-1</sup> measured application rates ranged from 51.8 to 106.7 kg ha<sup>-1</sup> of urea (46 % Nitrogen) fertiliser over 102 paddocks on four farms. Average field variation calculated over all paddocks was 37.9 %. Irregular paddock shape was found to have higher application variation (40.8 %) compared to regular shaped paddocks (35.9 %). Hot spot analysis was performed to identify areas receiving statistically significant high and low application rates ( $\sigma < 2.0$ ). Over all paddocks 7.4 % of total area received significantly high application rates while 10.2 % received significantly low application rates. This information, collected over a number of applications, could be incorporated into subsequent variable rate application maps where rates can be adjusted on areas that have received incorrect quantities of fertiliser in previous applications. This system will improve sustainability for a farm by ensuring that nutrient management plans can be followed as well as providing a means of traceability and proof of placement.

**Keywords.** fertiliser; application equipment; modelling; precision agriculture; geographical information systems.

### 6.1. INTRODUCTION

There is a basic assumption within precision agriculture that fertiliser application using a spinning disc

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<sup>10</sup> This chapter contains some changes to the published paper resulting from examiner emendations.

spreader is relatively uniform. Quality assurance programs and standard international test methods accept a coefficient of variation (CV) of 15% for fertiliser containing nitrogen and 25% for products that do not contain nitrogen. There are a number of fertiliser quality assurance programs used throughout the world. These include ISO 5690/1 (International), ASAE standard S341.2 (USA), ACCU-spread (Australia) and Spreadmark (New Zealand). A common feature of these systems is the measurement of the transverse spread pattern and calculation of swath width spacing to meet the standards of spreading accuracy set by the corresponding quality assurance programs.

Two fertiliser quality control programs operate in New Zealand, Fertmark (NZFQC, 2002) and Spreadmark (NZFQC, 2006). The purpose of Fertmark is to ensure fertiliser products meet declared chemical and physical specifications, while the Spreadmark program is to ensure quality placement of fertiliser. The objective of Spreadmark is to place fertilisers in locations where they can be of greatest agricultural benefit and the least environmental harm (NZFQC, 2006). The combination of these two programs aims to ensure that the right fertiliser is being dispersed in the correct location on the land.

These assurance programs measure and declare expected variation prior to field application, but make no attempt to evaluate actual field performance. Many attempts at calculating the effect of spreader performance do not consider the field performance but rather presume that transverse test performance is achieved. The objective of this work was to develop a method that could be used to measure field performance using spreader testing data while taking geographical position during application into account.

## **6.2. BACKGROUND**

There are environmental, agronomic and economic reasons why there is a need to place fertiliser accurately in the field. Richards (1985) reported that application rate errors have the greatest effect on crop yield but the unevenness of spreading may cause the greatest financial loss. Agronomically, localised under-dosage can limit the production of the crop because of a nutrient deficit, while over dosage can cause crop lodging and represent a risk of ground water pollution ultimately having an adverse environmental effect (Tissot et al., 2002).

Modern agriculture requires spreaders that perform well in order to optimise fertiliser use. However, current literature suggests that there are a number of voids in the information base regarding field-level

delivery of uniform, repeatable, and in some cases, accurate applications of granular fertilisers (Smith et al., 2004). Smith et al. (2004) also stated that different plants in different spatial locations can receive substantially different amounts of fertiliser due to variation from fertiliser applicators. This would indicate that even if the soil profile was uniform across a field significant spatial variation in plant nutrient uptake would exist.

Application uniformity is predominantly represented by the coefficient of variation (CV) of an overlapped spread pattern at certain swath spacing from a spreading vehicle. Under the Spreadmark quality assurance program (NZFQC, 2006) a CV of less than 15% needs to be obtained in order to spread nitrogenous fertilisers and less than 25% in order to spread non-nitrogenous fertiliser. These levels of variation are predominately measured on flat surfaces under controlled test conditions such as those used in tray testing (ASAE, 1999; ISO, 1985; NZFQC, 2006). There are many examples where field variation often exceeds these levels of accuracy. Parish and Bergeron (1991) concluded that CVs increased for a spinner-disc spreader from 10% to the upper 20s or lower 30s when moving from operating on a smooth surface to a rough surface. Sogaard & Kierkegaard (1994) reported CVs in the range of 15% to 20% are typical of field tests for spinner-disc spreaders, while Smith et al. (2000) acknowledged that CVs are higher for field operations compared to laboratory-derived CVs.

There are many parameters that have the potential to influence nutrient dispersal uniformity in the field, these can be categorised into four main areas, spreader design, fertiliser properties or, more usually, spreader maintenance and operation (Richards, 1985). A similar view was adopted by (Fulton et al., 2005) who stated that application precision is affected by both spreading equipment and the inherent variability of the product. Tissot et al. (2002) stated that spreading homogeneity is linked to spreader features, fertiliser characteristics and user skills and describes overall fertiliser distribution errors as being caused by either: too wide spreading width; insufficient spreading width; central peak (too much fertiliser in the centre line) or two peaks (too much fertiliser at a few meters distance on both sides of the spreader line). More recently, with the adoption of GPS guidance, variable rate application and GPS vehicle tracking, errors such as offset distance between the GPS antenna and the point of application, and the GPS system latency have become prominent (Fulton et al., 2003).

There have been attempts to characterise the relationship between machine variables and machine

settings using mathematical models (Aphale et al., 2003; Cunningham & Chao, 1967; Griffis et al., 1983; Olieslagers et al., 1996; Patterson & Reece, 1962; Pitt et al., 1995). The creation of these models has allowed for a far greater understanding of the interaction between product and machine characteristics. However, Tissot (1995) concluded that the use of equations of motion is not satisfactory when being used for the prediction of fertiliser in the field. Therefore, in order to understand the spatial distribution of fertiliser in the field another approach was required.

Many approaches to model fertiliser distribution in the field have been founded on the traditional tray measurement programs where multiple rows rather than a single row of collection trays are used to measure spatial uniformity. Smith et al. (2004) designed a fertiliser deposition test to determine the effect of both wind speed and direction on the lateral and transverse deposit uniformity of selected fertiliser materials when using a spinning disc spreader truck in the field. Transverse distribution measurements were completed in accordance with ASAE standard S341.2 (ASAE, 1999), but, six trays were then placed along the direction of travel at four transverse sample positions. Fulton et al. (2005) and Lawrence & Yule (2005) both describe a two dimensional matrix of trays laid out to assess spatial uniformity of a spread pattern. Fulton et al. (2005) described a 2D pan matrix used to capture the rate change from a variable rate applicator. Twelve transverse rows were laid in succession in accordance with ASAE standard S341.2 (ASAE, 1999). Fulton et al. (2005) stated that 12 transverse replications were sufficient for characterising uniform distribution patterns in the field. In order to conduct accurate transverse and longitudinal tests simultaneously, Lawrence & Yule (2005) used 1400 0.5 m x 0.5 m collection trays laid out edge to edge in a 80 x 18 tray matrix. Data from both methods was overlapped to calculate the CV at different swath widths. Since a 2-D matrix of collection trays was used rather than a 1-D row, a 2-D representation or surface could be created to illustrate the distribution patterns from a granular applicator or further, a 3-D representation could be created providing more insight into distribution issues, if any exist, that may be undetectable by plotting distribution patterns two dimensionally (Fulton et al., 2005). Previous experimental work by the authors indicated that longitudinal variation could be considered as noise rather than systematic. However, there may be a case for examining spreaders with chain feed mechanisms to check that an irregular feed does not have an effect on performance. Although all of these methods provide a good understanding of the variability of spreader performance in the field, they do not take driving accuracy or driving variation into account as overlap was calculated rather than

measured in the field.

A sensor that measures the initial velocity and diameter of fertiliser particles developed by Grift & Hofstee (1997) was simplified to be used on a spreader during field operations (Grift & Hofstee, 2002). The sensor predicted landing positions of individual particles using a mathematical model. Many mathematical models have been developed to predict the spread pattern as an alternative to tray measurements (Aphale et al., 2003; Cunningham & Chao, 1967; Griffis et al., 1983; Olieslagers et al., 1996; Patterson & Reece, 1962; Pitt et al., 1995). However, the sensor developed by Grift & Hofstee (2002) provided a real time measurement of particle variables that could be used as a validation tool of mathematical models, and also to examine distribution behaviour in the field. If the spreader was linked to a GPS unit this system would allow location of individual particles in the field to be calculated. However, the sensor only gave an indication of the relative dispersion of fertiliser material (Grift & Hofstee, 2002), therefore could not be used as a complete measure of field application variation.

Hensel (2003) described a methodology based on an image processing system that enabled images of the field surface to be analysed and objects lying on the surface, such as mineral fertiliser granules, to be distinguished from soil and plant particles. Results showed that on freshly cultivated soil 100% of particles could be detected, however, this was reduced as leaf area index (LAI) of the covering crop increased. The system was mounted on an All Terrain Vehicle (ATV) connected to a GPS allowing a fertiliser application map to be created giving an overall indication of spatial variability. This method required two passes by a vehicle in order to collect data and would have to be limited to freshly cultivated soils; data collection would need to be completed promptly after spreading in order for the fertiliser not to dissolve into the soil or air.

Fulton et al. (2003b) describes the two way communication between a variable rate controller on a spreader and its accompanying software having the ability to record actual application quantity. The data, represented spatially in a shape file can give a measurement of variation in application through the metering device. Fulton et al. (2003b) went further and developed a GIS method to post process fertiliser application data in order to create an "as applied" map from a variable rate applicator. A polygon shape file was created between each of the lodged GPS fixes at the width of the distributor. Each rectangular polygon was subdivided into thirteen parts; each sub-polygon was assigned an application rate based on the amount of material applied at the corresponding point. This method reported a relatively low  $R^2$  value (0.47) between

predicted and prescribed application rates, however, Fulton et al. (2003b) reported that shortcomings of the model may have contributed to the low application accuracy when compared to field collected data. The main shortcoming appeared to be the inability for the polygon shape file to circumnavigate corners along the spreader path.

### **Objectives**

- Develop a GIS measurement system to measure field dispersion accuracy using readily collected information.
- Use GIS model to calculate field CV from a commercial spreading vehicle.
- Analyse the major factors effecting accurate field application of fertilisers.

### **6.3. METHODOLOGY**

Transverse spread pattern data is collected on a bi-annual basis under the Spreadmark quality assurance program (NZFQC, 2006) for all types of fertilisers while, tracking data, collected from a GPS unit on the spreading vehicle is increasingly becoming a requirement for spreader operators due to regulation from local government and quality assurance programs. These two pieces of data formed the basis for the GIS model.

**Table 6.1. Paddock size information for four dairy farms in Waikato, New Zealand**

	No of Paddocks	Average size (ha)	Range in size (ha)
Farm A	23	1.83	0.88 – 7.45
Farm B	41	1.38	0.48 – 2.61
Farm C	19	2.13	0.73 – 4.18
Farm D	19	1.31	1.04 – 1.98

The spreading vehicle used was a 1317 Mercedes-Benz with a Bredal K65-1134 bin operating dual round spinner discs with 4 vanes on each disc at 1000 rev min<sup>-1</sup>. The spreader was equipped with a computer system to adjust application rate for forward speed, for the purposes of this analysis it was assumed that it worked correctly. RINEX GuideTrax software Version 1.0 (Rinex Technology, 2005) was installed in the vehicle, the software provided GPS guidance for the spreading vehicle through the use of a “virtual road” on an in cab display screen. The software also recorded spreader location information in a \*.gdx file. Point locations were recorded at 1 Hz, the current application rate and feed gate position (on/off) onto the spreader discs was also recorded. Locations were recorded from the GPS in geographic coordinates (WGS, 1984) and converted in

real time to the New Zealand Map Grid Geodic Datum 1949 (NZMG) projected coordinate system. Projecting data from WGS 1984 (decimal degrees) into a Euclidean coordinate system simplifies dimensional analysis, such as measuring distances and generating defined shapes within software code (Fulton et al., 2003).

Spreading data was collected from four dairy farms in the greater Waikato region of New Zealand, each farm used a rotational pasture grazing system necessitating small paddocks located on flat to undulating topography. Paddock size varied from 0.48 ha to 7.45 ha, however, average paddock size for all farms was between 1.3 ha and 2.2 ha (Table 6.1). Each paddock was classed as having a square/rectangular or irregular form. Form was determined by whether or not the spreading vehicle could follow the same A-B line throughout the entire paddock, if not, the paddock was deemed to be of irregular shape. Failing to follow the A-B line occurred for two reasons (a) the paddock shape or (b) undulating terrain. There were found to be 11, 10, 1 and 2 irregular shaped paddocks on farms A-D respectively. This information was used to calculate the effect of paddock shape and topography on spreading accuracy. In all spreading circumstances urea (46% Nitrogen) was spread at an application rate of  $80 \text{ kg ha}^{-1}$  ( $36.8 \text{ kg ha}^{-1}$  of Nitrogen). Urea is a granulated fertiliser commonly used on New Zealand pasture to boost dry matter production to meet projected feed deficits. It is most commonly used to promote late autumn and early spring growth.

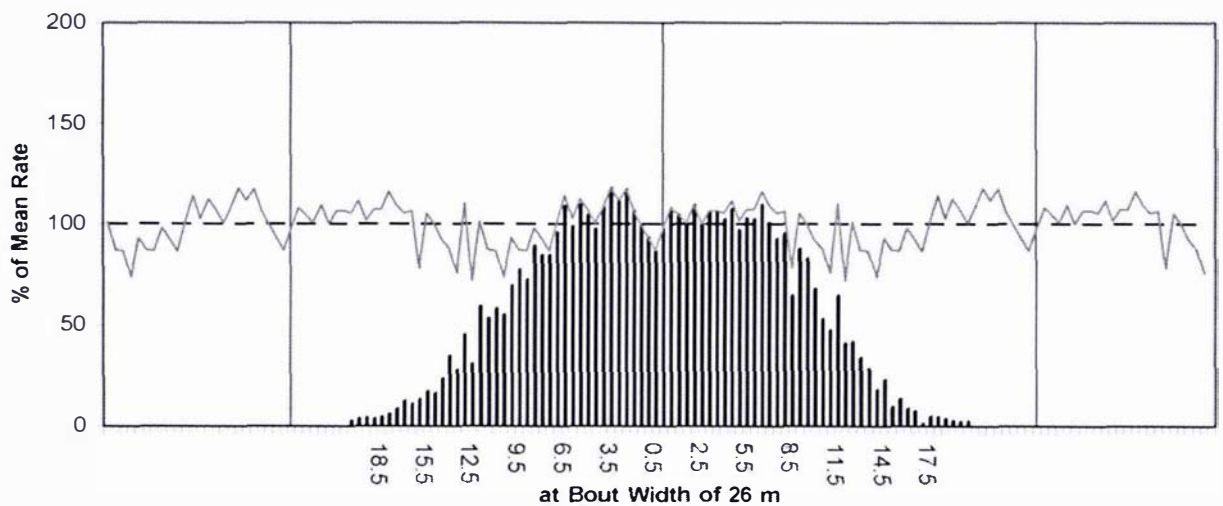


Figure 6.1. Transverse distribution pattern of a 1317 Mercedes-Benz with a Bredal K65-1134 bin operating at a 26 m swath width.

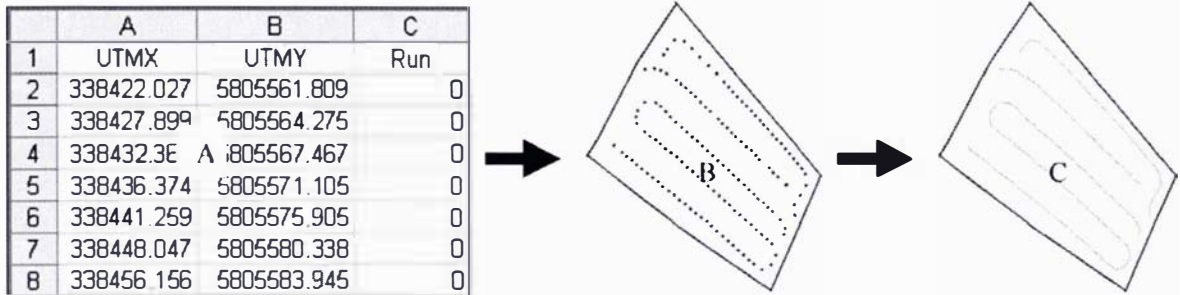
A spread pattern test was conducted on the spreading vehicle using urea in accordance with the Spreadmark Code of Practice (NZFQC, 2006). The vehicle was certified to spread at a swath width of 26 m; this is where the coefficient of variation for the transverse spread pattern was less than 15%. Figure 6.1 shows the spread pattern achieved from the spreading vehicle, the line represents the relative accuracy of the transverse spread pattern when overlapped at 26 m (15% CV).

ArcGIS (ESRI, 2005) was used as the Geographic Information System (GIS) to display the spatial data from the analysis. In order to display collected spatial data from the spreading vehicle it was necessary to convert the \*.gdx file obtained into either the \*.txt or \*.csv file format. A conversion program was written in Microsoft Visual Studio.NET (Microsoft Corporation, 2002) to perform this task. The program reshaped the \*.gdx file into only essential data and exported features to the \*.csv file format, this was able to be imported into ArcGIS (ESRI, 2005).

### ***Model Development***

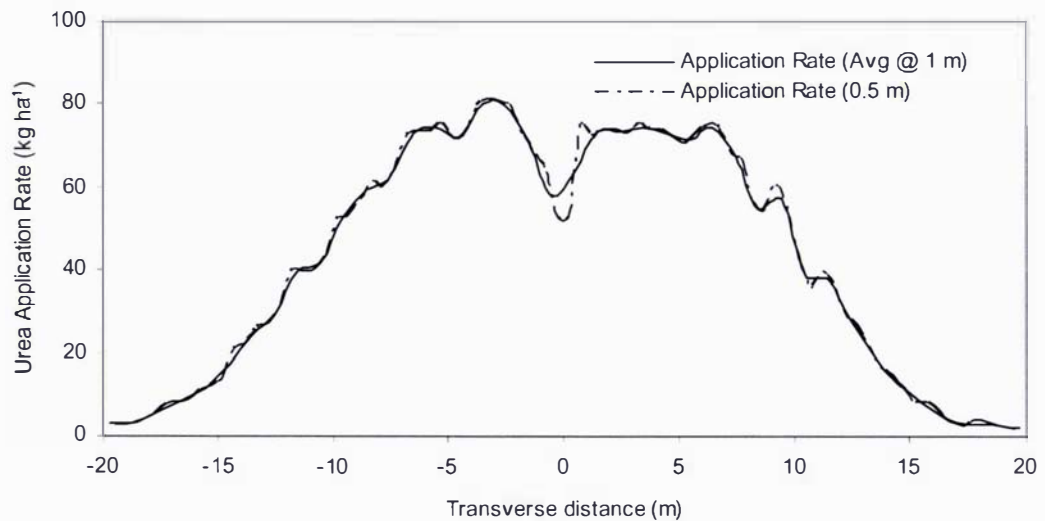
The model aimed to calculate field dispersion variation by overlaying the spread pattern onto the spread lines collected from the RINEX GuideTrax software (Rinex Technology, 2005) in ArcGIS (ESRI, 2005). This allowed the calculation of overall field CV, application rate accuracy, cross track error accuracy and the effect of paddock size and shape on field dispersion variation to be calculated.

Data from a total of 102 paddocks was collected over four farms, each individual paddock was able to be analysed; therefore, the process required automation. Using Model Builder (ESRI, 2005), a process automation program built inside ArcGIS (ESRI, 2005), the same process was replicated to be used on multiple paddocks. The first step in the analysis process was to project the collected GPS track data (Figure 6.2a) in ArcGIS (ESRI, 2005), the converted \*.csv file was imported and displayed as a point shape file using NZMG 1949 as a projected datum (Figure 6.2b). Collected points were converted to polylines (Figure 6.2c) using the 'Make one polyline from points' command in XTools Pro for ArcGIS desktop (Data East, 2005). Each of the polyline shape files from the four farms were displayed within their predefined paddock boundaries. Paddock boundaries were created from orthophotos acquired for each farm.



**Figure 6.2. Process to convert from \*.csv file (a) into point shapefile (b) into a polyline shapefile (c) to display spreader vehicle movements in a 2.25ha field.**

The first process of the model was to buffer each of the spread lines at specified intervals on both the left and right sides in order to create application zones the same as those recorded from a spread pattern test. This meant that the performance of both racetrack and circuitous driving patterns could be accurately represented. Buffers were created using the 'Buffer' tool command in ArcGIS (ESRI, 2005) at 1m intervals from the spread line. One metre intervals were chosen because of process time and model complexity in terms of building time available. Spread pattern data was collected at 0.5 m, therefore, values were summed and averaged every 1m in order to fit in the model. The averaging process was found to have little effect on the shape or achieved application rate of the distribution pattern as illustrated in Figure 6.3.



**Figure 6.3. Comparison of transverse pattern data when using 0.5 m and 1 m tray intervals. 1 m data used to model field fertiliser application.**

Post buffering the spread line, each buffer had a separate entity (Figure 6.4a). In order to obtain the correct application rate for each zone a proportional value was designated to each buffer, when buffers were summed together they produced the shape of the distribution pattern (Figure 6.4b). Individual buffers were appended together into one polygon shape file feature class, on the 2.25 ha field (Figure 6.2) there was a total of 389 attributes in the polygons layer. The next stage was to union all shape files together; a union computes a geometric intersection of all input features (ESRI, 2005). This is important when considering the overlap process that occurs during centrifugal fertiliser spreading as overlapped buffers are intersected and treated as one entity; this process increased the number of attributes in the shape file to 67,671. The following process used the 'multipart to single part' function in ArcGIS (ESRI, 2005); this function takes all the geometric intersections calculated from the unioned shape files and explodes them into individual rather than multiple parts. In order to identify identical polygons within the shape file the centroid coordinates (x,y) and area of each individual polygon were calculated and appended in a string within the attribute table of the shape file. The shape file was dissolved based on the unique string created within the attribute table; the application rate of each identical dissolved polygon was summed and appended to the newly created shape file. The new shape file was significantly reduced in size (2,273 attributes) and contained a single instance of all overlapped polygons and the respective summed application rate

A point grid covering the entire spread area was required in order to extract application rate values at equal intervals across the field. Different intervals were investigated to measure the effect on output statistics. Fulton et al (2003) chose a grid spacing of 3.05 m. It was found in this study that there was no significant difference in application statistics when a grid spacing of up to 10 m was used on a 2.25 ha paddock (Table 6.2), however, in order to maintain the integrity of the dataset, a grid spacing of 1.0 m was chosen.

At each 1.0 m sample point the summed application rate from the respective intersecting polygon was extracted and used for further analysis. Because fertiliser application data is continuous the kriging process was used to interpolate the discrete sample data into a smoothed application surface. The production of the application surface allows application statistics to be generated for individual fields. The application surface was also categorised into application rate ranges in order to perform spatial 'hot spot' analysis on each of the four farms. Hot Spot analysis identifies spatial clusters of statistically significant high or low attribute values (ESRI, 2005), in this case, fertiliser application rate. Figure 6.5 shows the complete modelling process to

create the fertiliser application map.

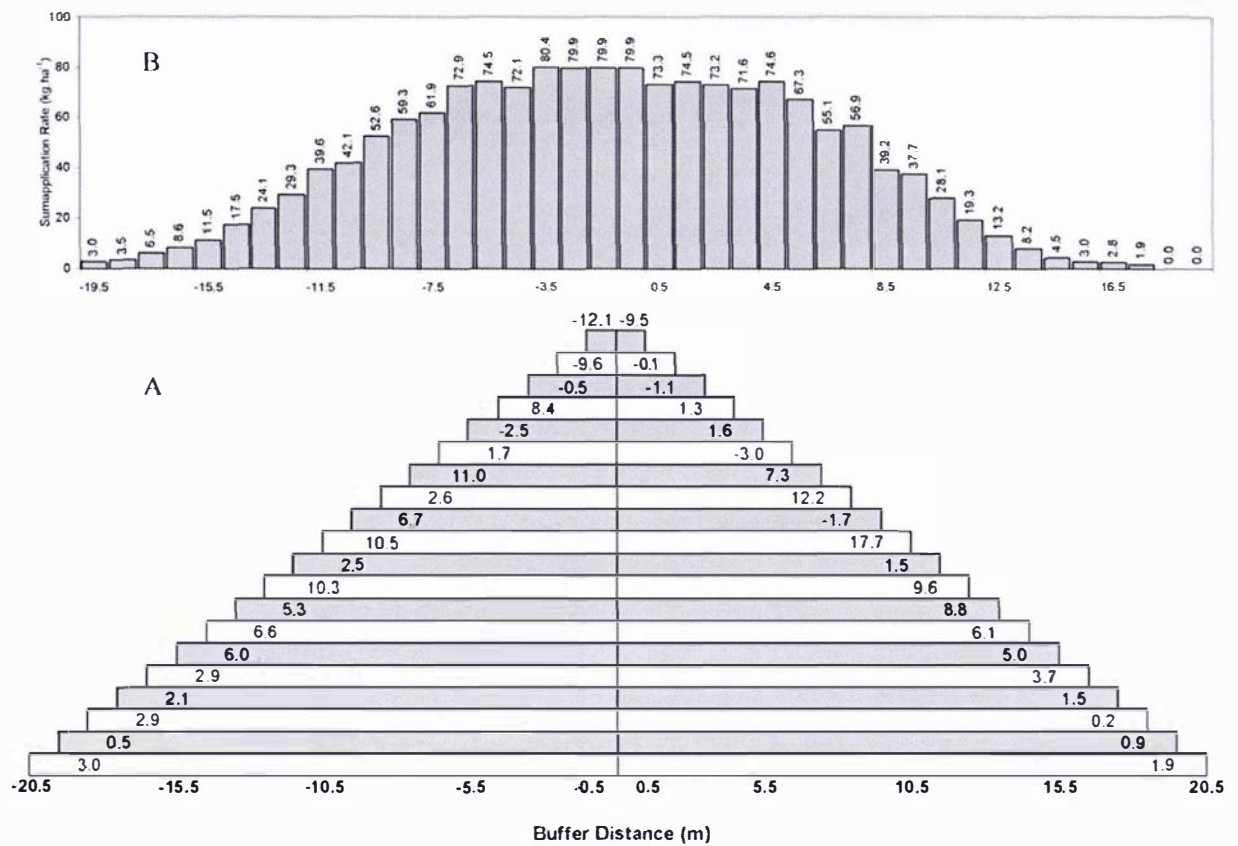
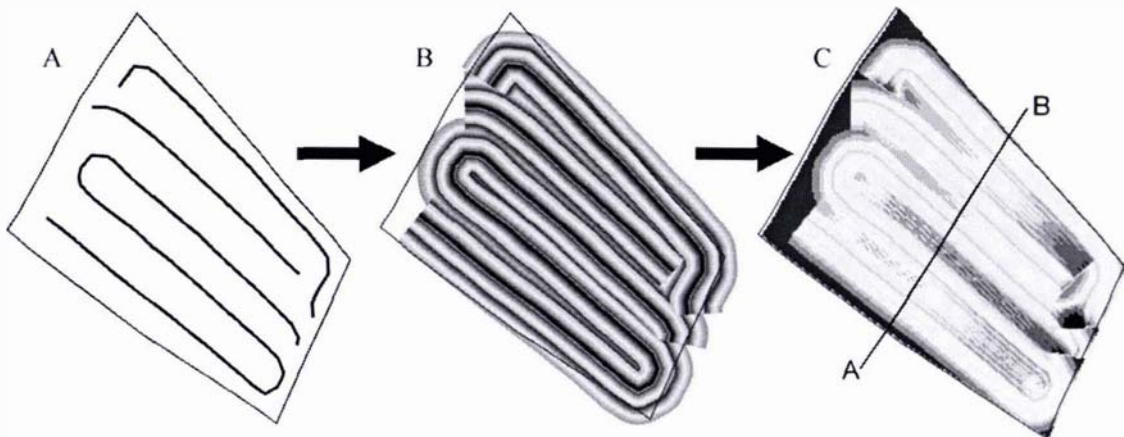


Figure 6.4. (a) Construction of individual buffers with respective proportional application rates required to produce an application pattern (b) the same as expressed by the spreading vehicle.

Table 6.2. The effect of sample grid spacing on extracted fertiliser application statistics on a 2.25 ha field.

Grid Spacing (m)	Number of Sample Points	Mean Application rate ( kg ha <sup>-1</sup> )	Standard Deviation ( kg ha <sup>-1</sup> )
1	22517	129.9	44.7
2	5626	129.9	44.6
3	2502	129.8	44.5
4	1408	129.8	44.5
5	901	129.4	45.0
8	354	130.0	46.0
10	226	128.7	45.9



**Figure 6.5.** Process used to create a field fertiliser application map on a 2.25ha field; (A) raw track data; (B) adjacent buffers from track lines; (C) kriged application map.

The kriged application surface was used to extract application rate statistics. An application graph for individual paddocks showing the variation in application (Figure 6.6) was created and statistics extracted. The mean application rate and standard deviation were used to calculate the coefficient of variation in fertiliser dispersion for individual fields. Levels of variation at farm scale were also calculated from the dataset. The actual field application was compared to that of an ideal performance across the paddock. Variation was compared by taking a transect across the paddock (Figure 6.5c). The transect was used to extract application information every 0.5 m from the kriged application map, data was then compared to the simulated test data overlapped at 26 m (Figure 6.7). The actual application rate was far in excess of the desired rate as a result of driving at a reduced swath width.

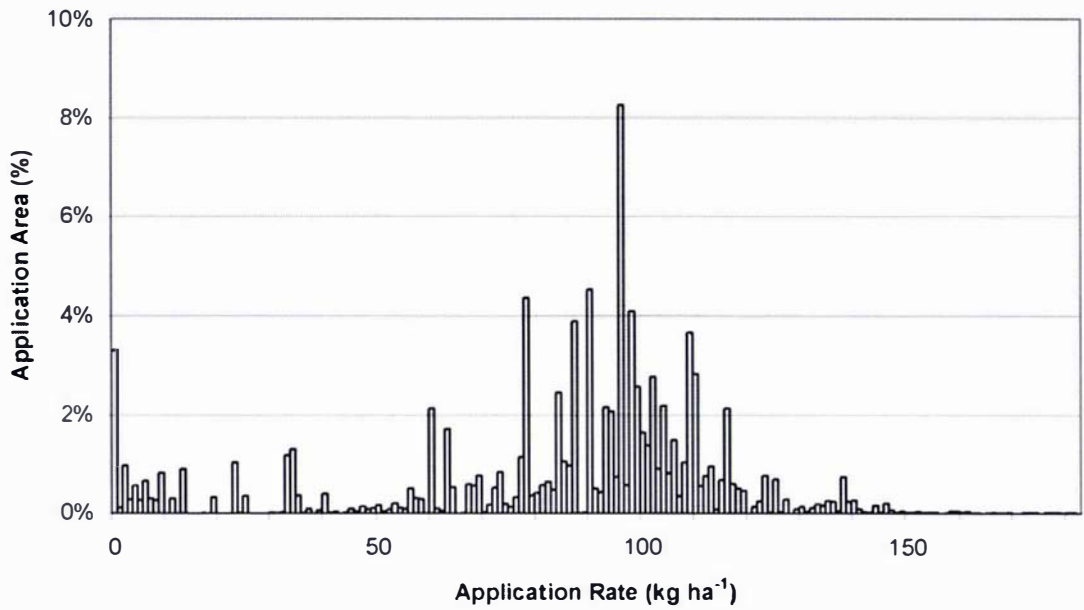


Figure 6.6. Percentage area receiving individual fertiliser application rates extracted from kriged application map.

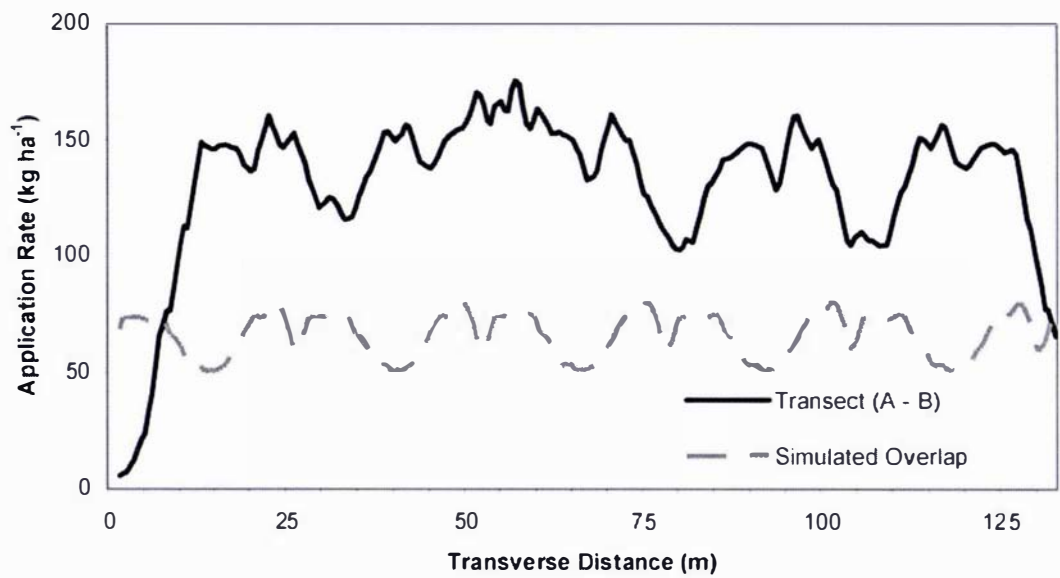


Figure 6.7. Difference in application rate between the simulated test overlap pattern and extracted values from a kriged application map using an A-B transect line.

#### 6.4. RESULTS AND DISCUSSION

The model was developed and tested on 102 paddocks over four farms in order to predict field application variation of fertiliser. Overall application variation was 37.9%; variation from the transverse spread pattern alone was 15% at a swath width of 26 m, therefore, variation due to driving accuracy and driving method was calculated to be 22.9%. The lowest calculated in-field CV on all farms was 20.8% on a 2.94 ha regular shaped paddock on Farm C. The highest calculated in-field variation (62.3%) was on a 0.8 ha irregularly shaped paddock on Farm B. The target application rate for all farms was 80 kg ha<sup>-1</sup> of urea (46% N); actual application was 72.3 kg ha<sup>-1</sup> ranging from 51.8 kg ha<sup>-1</sup> to 106.7 kg ha<sup>-1</sup> on individual paddocks. Farm D had the lowest average paddock application CV (36.2%) followed by farms B, A and C respectively (Table 6.3).

**Table 6.3. Variation in field application and application rate of urea (46%N) over four farms**

		Average	Minimum	Maximum	Std Dev
<b>Farm A</b>	App Rate (kg ha <sup>-1</sup> )	91.7	77.7	106.7	7.3
	Field CV	37.1%	24.6%	50.1%	6.9%
<b>Farm B</b>	App Rate (kg ha <sup>-1</sup> )	68.1	55.1	83.0	6.2
	Field CV	36.9%	22.9%	62.3%	9.6%
<b>Farm C</b>	App Rate (kg ha <sup>-1</sup> )	60.9	51.8	71.5	5.2
	Field CV	43.0%	20.8%	58.9%	10.1%
<b>Farm D</b>	App Rate (kg ha <sup>-1</sup> )	69.1	62.0	88.6	5.9
	Field CV	36.2%	25.3%	47.6%	5.9%
<b>All Farms</b>	App Rate (kg ha <sup>-1</sup> )	72.3	51.8	106.7	12.5
	Field CV	37.9%	20.8%	62.3%	8.8%

Table 6.4 shows the effect of paddock shape and size on field application variation, a paddock size of between 2 and 4ha obtained the lowest average level of variation for both regular and irregular shaped paddocks (34.4% and 33.4% respectively). On regular shaped paddocks, average field variation decreased as paddock size increased, however, this trend was not followed on irregular shaped paddocks. There was found to be a 4.9% difference overall between application variation on regular and irregular shaped paddocks. Seventeen regular shaped paddocks (where a set A-B line could be followed and therefore a more regular driving pattern can be achieved) had field variations less than 30%, however, only four irregular shaped paddocks had calculated field variation less than 30%. A 5% difference in the average variation between regular and irregular shaped paddocks was observed (35.9% and 40.8% respectively), therefore, it is stated that paddock shape does have an impact on field CV.

**Table 6.4. The effect of paddock size on field application variation over 102 paddocks.**

Paddock Shape	Paddock Size	No of Paddocks	Average CV
Regular	<1ha	1	38.9%
	1-2ha	49	36.1%
	2-4ha	9	34.4%
	>4ha	0	-
<b>All Regular Paddocks</b>	<b>0.96 - 3.17ha</b>	<b>59</b>	<b>35.9%</b>
Irregular	<1ha	9	39.0%
	1-2ha	28	41.5%
	2-4ha	3	33.4%
	>4ha	3	46.4%
<b>All irregular Paddocks</b>	<b>0.48 – 7.45ha</b>	<b>43</b>	<b>40.8%</b>

A hot spot analysis was performed on the dataset for each farm. The  $G_i^*$ <sup>11</sup> statistic, calculated from the analysis, was used to determine regions of high (or low) fertiliser application. These were identified if the  $G_i^*$  statistic for the area was outside two standard deviations from the mean of the dataset. On average 10.2% of a paddock's total area was found to be in the low application zone while 7.4% of the total area was calculated as being in the high application zone. A 1.06 ha paddock on Farm B had the largest proportion of low application zones (26.8%) (Figure 6.8a), while a 1.14 ha paddock on Farm A had the highest proportion of high application zones (49.1%) (Figure 6.8b). It was calculated that regular shaped paddocks only had 8.9% and 5.8% of high and low application zones compared to 11.0% and 12.3% respectively for irregular shaped paddocks.

Farms B, C and D had a very similar application rate distribution (Figure 6.9) where the majority of fertiliser ( $\approx 60\%$ ) was spread between 70 and 90 kg ha<sup>-1</sup>. However, farm A had a considerably different application rate distribution with only 23% of the total area receiving between 70 and 90 kg ha<sup>-1</sup>. The majority of application rates achieved on farm A (46.7%) were between 100 and 120 kg ha<sup>-1</sup>, this indicates a significant proportion of the total area receiving the target rate (80 kg ha<sup>-1</sup>). This high level of application was reflected in the mean paddock application rate for farm A (91.7 kg ha<sup>-1</sup>) being higher than the target application rate even when considering the border effect caused by paddock boundaries.

<sup>11</sup> A spatial statistic used to measure the local intensity of clustered cells on a raster surface to measure if clusters are significantly high/low compared to the mean value of the raster (Getis & Ord, 1992).

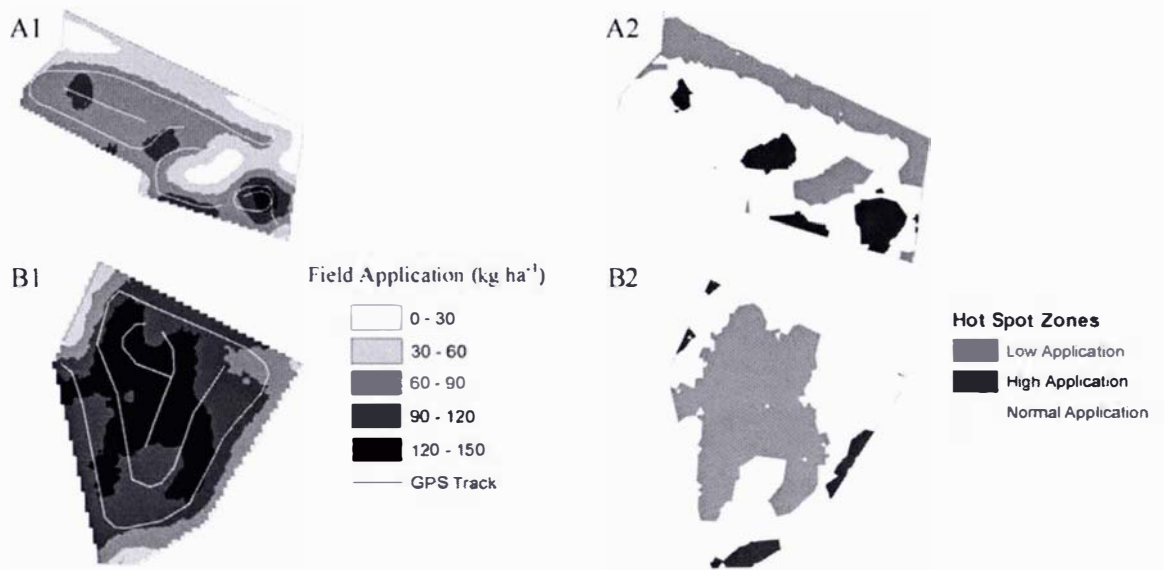


Figure 6.8. Fertiliser application map (A1 & B1) converted to areas of high and low application (A2 & B2) using 'hotspot analysis'. A2 is a 1.06 ha paddock where 26.8% of the total area received low application rates. B2 is a 1.14 ha paddock where 49.1% of the total area received high application rates.

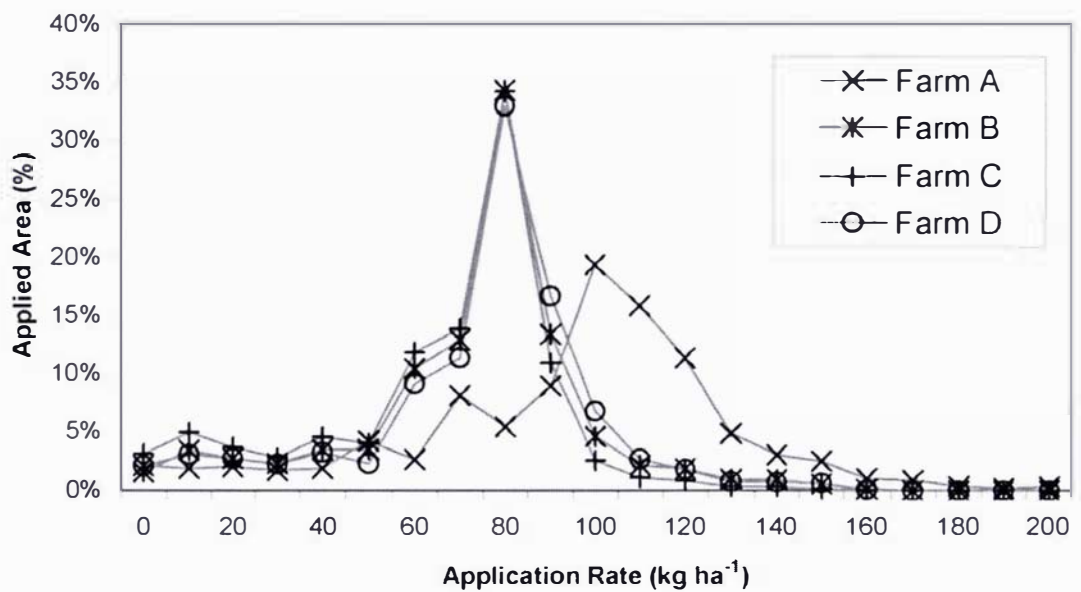


Figure 6.9. Application rate distribution of urea over four farms where the target application rate was 80 kg ha<sup>-1</sup>.

Results indicated that driving accuracy and paddock shape contribute more to application variation than the variability of the spreading vehicle. Although many have acknowledged that field application variation is higher than that expressed by a single transverse distribution test (Parish & Bergeron, 1991; Smith et al., 2000; Sogaard & Kierkegaard, 1994), it has been difficult to put sound figures on actual levels of variation. Parish (1999) stated that field variation could be anywhere between the high 20's to the early 30's for field application variation. Results from this study indicate an overall CV of 37.9% ranging from 20.8% to 62.3% on individual paddocks. Previous precision agriculture systems have always assumed uniform spread but results would indicate that this is not possible at a practical level.

Due to the increased environmental concern surrounding fertiliser use there is now a demand for nutrient budgeting. Results from this study indicate that the levels of variation measured using the modelling process would warrant inclusion in fertiliser traceability programs in order to ensure set budgets are adhered to. The New Zealand Dairy industry has the aim of reducing Nitrogen and Phosphate loss to less than 50% of current levels within a ten year period (Dairy Insight, 2006). One of the objectives is to use nutrient budgeting along with nutrient modelling to assist in the management of reducing nutrient loss. However, if nutrient budgets do not take account of application and response rate variations to fertiliser, their potential in terms of providing management solutions will be blunted.

The method can also be used to calculate economic efficiencies of fertiliser use using spatial measurement techniques of yields such as those from crops and more recently, pasture (Yule et al., 2005). Using the method described, the utilisation of converting nitrogen fertiliser into extra crop/pasture can be easily calculated at a spatial level accounting for spreading variation. In the case of phosphatic fertilisers it is possible that the continued uneven application will have an effect on soil test results, therefore, geo-referenced soil sampling could be guided from application zones rather than at random. This may help to explain variations which are not soil related or the subject of "apparently" random variation. This will again help to calculate the true fertiliser response in any one position within a paddock.

### **6.5. CONCLUSION**

The model presented is capable of representing the spatial pattern of the fertiliser application from a spreading vehicle using the actual spread pattern and the driving track recorded from the spreader. Analysis of field results indicates that far from being uniform, the actual application variation is heavily influenced by driving pattern, driving accuracy, paddock size and paddock shape. Small paddocks set up for rotational grazing made it difficult to achieve uniform spreading. Using this software as part of a precision agriculture system allows the user to monitor fertiliser application on a spatial basis. If each application is considered as a layer within a GIS system then the total fertiliser application can be spatially represented. Subsequent applications can take account of this and variable rate application technology utilised to ensure a more even application of nutrients over a given time period. Information is collected in a form that can be easily combined with pasture growth or other yield mapping information so that true fertiliser utilisation can be calculated in any location on the farm rather than that assumed from average application rates, this is valuable for calculating fertiliser programs and potential nutrient loss.

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## CHAPTER 7

# MODELLING OF FERTILISER DISTRIBUTION USING MEASURED MACHINE PARAMETERS.

### *Paper Reference*<sup>12</sup>

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Lawrence, H. G., I. J. Yule. (2007). Modelling of fertiliser distribution using measured machine parameters.

Transactions of the American Society of Agricultural and Biological Engineers, 50(4): 1–7. *Received*  
*25 July 2006; accepted May 2007*

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**Abstract.** *Collecting accurate fertiliser distribution information from large field trials is difficult and very labour intensive. A computer analysis method was developed for analysing field application variation of fertiliser distribution from any spreading vehicle. The tool used measured machine parameters including geographical position and heading and a series of static spread pattern tests from the spreading vehicle. A field distribution calculator and geographic mapping tool were created to firstly calculate fertiliser material distributed in each 0.5 m quadrant of a field and secondly produce an application surface. The tool proved to be effective for calculating an accurate representation of field application variation and should have many uses in fertiliser application.*

**Keywords.** *Fertiliser; GPS; GIS; static distribution; fertiliser application model.*

### **7.1. INTRODUCTION**

The study of fertiliser and spreader interaction on a field scale has long been deemed problematic as the physical area required to be analysed is often large, therefore, labour intensive. Currently, methods such as transverse tray testing (ASAE, 1999; ISO, 1985), mathematical modelling (Aphale et al., 2003; Cunningham & Chao, 1967; Griffis et al., 1983; Olieslagers et al., 1996; Patterson & Reece, 1962; Pitt et al., 1995) and discrete element modelling (Tijskens et al., 2005) have been used to successfully explain the interaction of key spreader machine parameters (i.e. disc, vane and orifice etc.) on fertiliser particle distribution in controlled testing environments. Many assumptions regarding the accuracy of field application variation are

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<sup>12</sup> *This chapter contains some changes to the published paper resulting from examiner emendations.*

based on the results obtained from controlled testing. However, these assumptions are often found to be inadequate due to the variable nature of the spreading vehicle interacting with the environment (topography, field shape, swath width variances, speed variation, and field condition).

Geographic Information System (GIS) interpolation techniques have been used successfully to more accurately calculate application variation of fertiliser spreaders in the field (Fulton et al., 2003; Lawrence & Yule, 2006). In both these cases a Geographic Positioning System (GPS) was used to measure true vehicle locations in the field, transverse distribution patterns were represented as polygon shapefiles and interpolated to create application surfaces. However, neither method allowed for the inclusion of measured machine parameters (i.e. variation in flow ( $\text{kg s}^{-1}$ ), forward speed ( $\text{m.s}^{-1}$ ) or disc speed ( $\text{rev min}^{-1}$ ) to be included and accounted for in the created application surfaces.

The purpose of this chapter is to illustrate an advanced GIS interpolation method to create fertiliser application surfaces with increased accuracy and efficiency than those developed previously. The method uses GPS data tagged with measured machine parameters to enhance the precision of modelling field application variability.

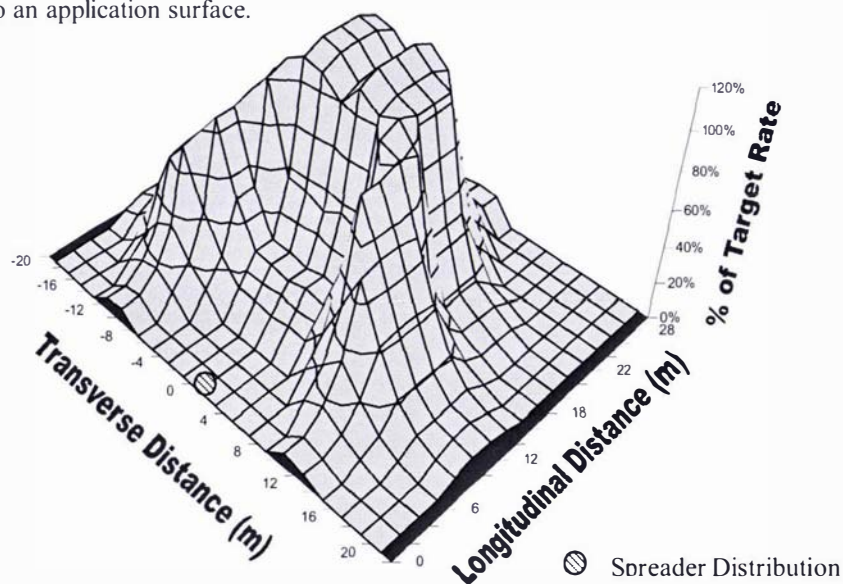
## **7.2. METHOD DESIGN AND IMPLEMENTATION**

The method was designed to incorporate the influence of tested machine parameters (flow rate, disc speed, vane pitch vane length etc.) and field discrepancies (speed variation, swath distance) on field application variability. A GPS track log from a Bredal K65-1134 dual spinning disc fertiliser spreader was recorded using RINEX GuideTrax software Version 1.0 (Rinex Technology, 2005) while operating under field conditions (Figure 7.1). Geographic spreading positions were recorded in a projected co-ordinate system (NZMG 1949) every second and recorded in a text file. Supporting information was geo tagged to each fix position, this included, GMT time (HH:MM:SS), vehicle forward speed ( $\text{m s}^{-1}$ ), heading direction ( $^{\circ}$ ), spinner disc speed ( $\text{rev min}^{-1}$ ) and fertiliser flow rate ( $\text{kg min}^{-1}$ ). Static spread test information was obtained for the spreading vehicle used in the analysis (Figure 7.2).



**Figure 7.1. Collected GPS track log from a Bredal K65-1134 dual spinning disc fertiliser spreader using RINEX GuideTrax software on a 3.48 ha paddock.**

Using the information gathered a “Field Distribution Calculator” was written in VB.NET (Microsoft Corporation, 2002) to calculate fertiliser mass landing in a quadrant of 0.5 x 0.5 m quadrants behind the spreading vehicle, this is the same size as a tray used during spreader tests. To achieve this, the static spread pattern from the vehicle was divided into 0.5 x 0.5 m quadrants with each quadrant given an X, Y location representing distance from the spreading vehicle. The mass and shape of the distribution behind the spreader was varied based on the vehicle forward speed, spinner disc speed, and fertiliser flow rate. Every 0.5 m interval along the GPS track log, a new set of static spread quadrant masses was calculated from geo tagged data. Calculated tray masses were collated in a text file and imported to ArcGIS (ESRI, 2005). A “Field Application Analysis tool” was created using ArcGIS Model Builder (ESRI, 2005) to interpret collated information into an application surface.

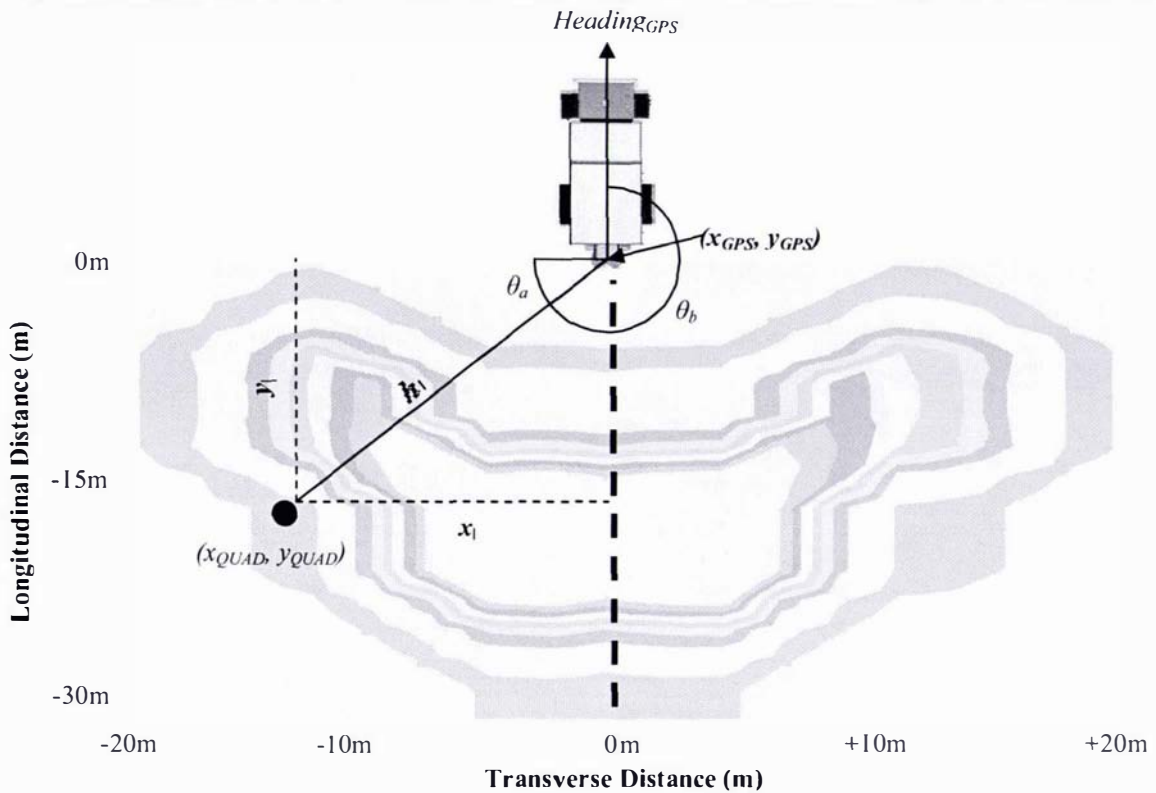


**Figure 7.2. Modelled static spread pattern for Urea from a Bredal K65-1134 dual spinning disc fertiliser spreader.**

### **Field Distribution Calculator**

The field distribution calculator required two key calculations to calculate the geographic landing position and fertiliser mass distributed for each 0.5 x 0.5 m quadrant of the static distribution pattern, these were: the calculation of the distribution quadrant and the calculation of masses contained in each quadrant across the field.

*Calculation of distribution quadrant* – The spreader footprint was 781.5 m<sup>2</sup> and contained 3126 individual 0.5 x 0.5 m quadrants, each quadrant was represented as a point in the centre of each quadrant with a known X, Y distance from the spreading vehicle ( $x_{QUAD}$ ,  $y_{QUAD}$ ). This location needed to be converted to geographic X, Y coordinates based off the geographic location (NZMG 1949) and heading (°) of the spreading vehicle. Several variables were required in order to perform the geographic coordinate calculation. Figure 7.3 shows both required and calculated variables needed to complete the mathematical operation. Known variables included the geographic location of the spreading vehicle ( $x_{GPS}$ ,  $y_{GPS}$ ), the direction of the spreading vehicle ( $Heading_{GPS}$ ) and the RAW (no datum defined) coordinates of each quadrant from the spreading vehicle ( $x_i$ ,  $y_i$ ). The variables that required calculating were the distance of each quadrant from the spreading vehicle ( $h_i$ ), the internal angle from the point of distribution to individual quadrants ( $\theta_a$ ) and the true angle between the GPS heading of the spreading vehicle and each individual quadrant ( $\theta_b$ ). All described variables were used to calculate the geographic location of individual static spread pattern quadrants ( $x_{QUAD}$ ,  $y_{QUAD}$ ).



**Figure 7.3.** Schematic diagram of known and required variables used to calculate the geographic position of 0.5 x 0.5 m quadrants of a static spread pattern from a spreading vehicle when applying fertiliser under field conditions.

The following steps describe the required calculations to obtain  $x_{QUAD}$  and  $y_{QUAD}$ :

1. The distance ( $h_1$ ) of each individual quadrant from the point of distribution ( $x_{GPS}$ ,  $y_{GPS}$ ) was calculated using Pythagoras theorem (1)

$$h_1 = \sqrt{x_1^2 + y_1^2} \quad (1)$$

2. The angle ( $\theta_a$ ) between individual quadrants ( $x_{QUAD}$ ,  $y_{QUAD}$ ) and the spreading vehicle was calculated using fundamental trigonometry theory (2). A negative angle indicated that the quadrant was to the right of the centre line.

$$\tan \theta_a = y_1 / x_1 \quad (2)$$

3. The true angle ( $\theta_b$ ) of each quadrant from the heading angle to the spreading vehicle was calculated (3). Eight case statements were required depending on the direction of travel ( $Heading_{GPS}$ ) and whether  $\theta_a$  was on the left or right hand side of the distribution line (2).

---

```

IF  $Heading_{GPS} \leq 90^\circ$  AND  $\theta_a \leq 0^\circ$  THEN  $\theta_b = Heading_{GPS} - Abs(\theta_a)$ 
IF  $Heading_{GPS} \leq 90^\circ$  AND  $\theta_a > 0^\circ$  THEN  $\theta_b = 180 - (Heading_{GPS} + 90 + Abs(\theta_a))$ 
IF  $Heading_{GPS} \leq 180^\circ$  AND  $\theta_a \leq 0^\circ$  THEN  $\theta_b = Heading_{GPS} - 90 - Abs(\theta_a)$ 
IF  $Heading_{GPS} \leq 180^\circ$  AND  $\theta_a > 0^\circ$  THEN  $\theta_b = 270 - (Heading_{GPS} + 90 + Abs(\theta_a))$ 
IF  $Heading_{GPS} \leq 270^\circ$  AND  $\theta_a \leq 0^\circ$  THEN  $\theta_b = Heading_{GPS} - Abs(\theta_a) - 180$ 
IF  $Heading_{GPS} \leq 270^\circ$  AND  $\theta_a > 0^\circ$  THEN  $\theta_b = 360 - (Heading_{GPS} + 90 + Abs(\theta_a))$ 
IF  $Heading_{GPS} \leq 360^\circ$  AND  $\theta_a \leq 0^\circ$  THEN  $\theta_b = Heading_{GPS} - Abs(\theta_a) - 270$ 
IF  $Heading_{GPS} \leq 360^\circ$  AND  $\theta_a > 0^\circ$  THEN  $\theta_b = 360 - Heading_{GPS} - Abs(\theta_a)$  (3)

```

4. The final calculation was used to obtain the geographic positions ( $x_{QUAD}$ ,  $y_{QUAD}$ ) of each 0.5 x 0.5 m distribution quadrant. Again, eight case statements were required for the calculation. The distance to each quadrant ( $h_1$ ) and the true quadrant angle ( $\theta_b$ ) were the key variables required for this calculation.

```
IF  $Heading_{GPS} \leq 90^\circ$  AND  $\theta_a \leq 0^\circ$  THEN
```

$$x_{QUAD} = x_{GPS} - h_1 * \cos(\theta_b)$$

$$y_{QUAD} = y_{GPS} + h_1 * \sin(\theta_b)$$

```
IF  $Heading_{GPS} \leq 90^\circ$  AND  $\theta_a > 0^\circ$  THEN
```

$$x_{QUAD} = x_{GPS} + h_1 * \sin(\theta_b)$$

$$y_{QUAD} = y_{GPS} - h_1 * \cos(\theta_b)$$

```
IF  $Heading_{GPS} \leq 180^\circ$  AND  $\theta_a \leq 0^\circ$  THEN
```

$$x_{QUAD} = x_{GPS} + h_1 * \sin(\theta_b)$$

$$y_{QUAD} = y_{GPS} + h_1 * \cos(\theta_b)$$

```
IF  $Heading_{GPS} \leq 180^\circ$  AND  $\theta_a > 0^\circ$  THEN
```

$$x_{QUAD} = x_{GPS} - h_1 * \cos(\theta_b)$$

$$y_{QUAD} = y_{GPS} - h_1 * \sin(\theta_b)$$

```
IF  $Heading_{GPS} \leq 270^\circ$  AND  $\theta_a \leq 0^\circ$  THEN
```

$$x_{QUAD} = x_{GPS} + h_1 * \cos(\theta_b)$$

$$y_{QUAD} = y_{GPS} - h_1 * \sin(\theta_b)$$

IF  $Heading_{GPS} \leq 270^\circ$  AND  $\theta_a > 0^\circ$  THEN

$$x_{QUAD} = x_{GPS} - h_1 * \sin(\theta_b)$$

$$y_{QUAD} = y_{GPS} + h_1 * \cos(\theta_b)$$

IF  $Heading_{GPS} \leq 360^\circ$  AND  $\theta_a \leq 0^\circ$  THEN

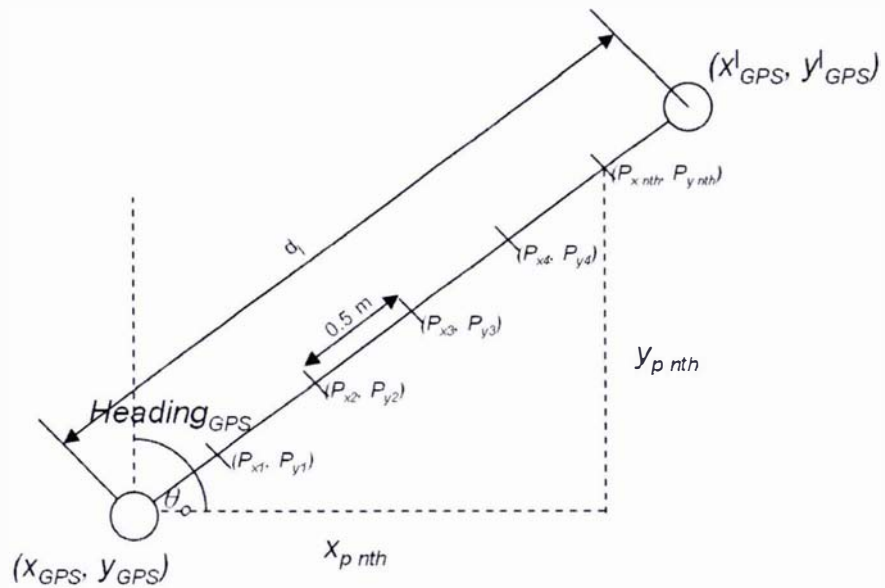
$$x_{QUAD} = x_{GPS} - h_1 * \sin(\theta_b)$$

$$y_{QUAD} = y_{GPS} - h_1 * \cos(\theta_b)$$

IF  $Heading_{GPS} \leq 360^\circ$  AND  $\theta_a > 0^\circ$  THEN

$$x_{QUAD} = x_{GPS} + h_1 * \cos(\theta_b)$$

$$y_{QUAD} = y_{GPS} + h_1 * \sin(\theta_b) \quad (4)$$



**Figure 7.4.** Schematic diagram of known and required variables used to calculate intermediate points required between each known GPS location  $(x_{GPS}, y_{GPS})$

*Calculating quadrant mass* – The mass for each quadrant was based on the static spread pattern of the spreader (Figure 7.2). However, the calculated spread pattern could be varied depending on disc speed (rev  $\text{min}^{-1}$ ), flow rate onto the discs ( $\text{kg s}^{-1}$ ) and forward speed variation ( $\text{m s}^{-1}$ ), parameters which can be recorded at each GPS location. Individual static spread patterns are required for each flow rate and disc speed used in field application. GPS locations were recorded approximately every one second, travel speeds were on average  $6.02 \text{ m s}^{-1}$  ( $21.7 \text{ km hr}^{-1}$ ), therefore, intermediate points were required between each GPS fix location

in order to maintain a consistent 0.5 m interval (Figure 7.4). Disc speed and fertiliser flow rate remained constant in this test. Known variables for this calculation included: individual static spread pattern quadrant mass ( $S_{WEIGHT}$ ), static spread pattern collection time period ( $t_{STATIC}$ ), GPS fix locations ( $x_{GPS}$ ,  $y_{GPS}$ ), time between GPS fix locations ( $t_i$ ) and vehicle heading ( $heading_{GPS}$ ). Variables that were required to be calculated from this data included: the absolute distance between GPS fix locations ( $d$ ), number of intermediate points between each fix location ( $P_i$ ), intermediate fix locations ( $P_x$ ,  $P_y$ ) and total material mass dispersed at each fix location ( $m_{QUAD}$ ).

The following steps describe the calculation of  $M_{QUAD}$  at every 0.5 m interval along the spreading path:

1. Initially the absolute distance ( $d$ ) between each GPS fix location was calculated (5).

$$|d| = \sqrt{(x_{GPS} - x_{GPS}^j)^2 + (y_{GPS} - y_{GPS}^j)^2} \quad (5)$$

2. Based on the known distance between ( $d$ ) the number of 0.5 m intervals ( $P_i$ ) between each GPS fix location ( $x_{GPS}$ ,  $y_{GPS}$ ) was calculated (6).

$$P_i = d / 0.5 \quad (6)$$

3. The geographic location of intermediate points  $P_x$ , and  $P_y$  were calculated  $P_{i\ nth}$  times between each GPS fix location, four case statements were required depending on the spreading vehicles heading ( $heading_{GPS}$ ) (7).

$$\text{IF } heading_{GPS} \leq 90^\circ$$

$$P_{x\ nth} = x_{GPS} + (\cos(\theta_c) \times (0.5 \times P_{i\ nth}))$$

$$P_{y\ nth} = y_{GPS} + (\sin(\theta_c) \times (0.5 \times P_{i\ nth}))$$

$$\text{IF } heading_{GPS} \leq 180^\circ$$

$$P_{x\ nth} = x_{GPS} + (\sin(\theta_c) \times (0.5 \times P_{i\ nth}))$$

$$P_{y\ nth} = y_{GPS} - (\cos(\theta_c) \times (0.5 \times P_{i\ nth}))$$

$$\text{IF } heading_{GPS} \leq 270^\circ$$

$$P_{x\ nth} = x_{GPS} - (\cos(\theta_c) \times (0.5 \times P_{i\ nth}))$$

$$P_{y\ nth} = y_{GPS} - (\sin(\theta_c) \times (0.5 \times P_{i\ nth}))$$

IF  $Heading_{GPS} \leq 360^\circ$

$$P_{x\ nth} = x_{GPS} - (\sin(\theta_c) \times (0.5 \times P_{1\ nth}))$$

$$P_{y\ nth} = y_{GPS} + (\cos(\theta_c) \times (0.5 \times P_{1\ nth})) \quad (7)$$

4. Finally, the total material dispersed ( $m_{QUAD}$ ) for each point ( $P_x, P_y$ ) at 0.5 m intervals along the spread path was calculated (8). This was based on the static spread pattern for the current disc speed ( $\text{rev min}^{-1}$ ) and flow rate ( $\text{kg s}^{-1}$ ).

$$m_{QUAD} = S_{WEIGHT} \times \left( \frac{t_i / t_{STATIC}}{P_i} \right) \quad (8)$$

A two dimensional output text file from both calculations was created, the file included three columns of data;  $x_{QUAD}$ ,  $y_{QUAD}$  and  $m_{QUAD}$  that could be easily added to any GIS platform.  $x_{QUAD}$  and  $y_{QUAD}$  represent the geographic locations for individual 0.5 x 0.5 m quadrants whilst  $m_{QUAD}$  represents individual quadrant masses. Because spread patterns were overlapped, many points were contained within each quadrant, therefore had to be interpolated using the field application mapping tool.

#### Field Application Mapping Tool

The field application mapping tool interpolated spatial data calculated from the field distribution calculator in a GIS platform. The raw point file (calculated from the field distribution calculator) and polygon field boundaries were required in order for the process to run. A graphical user interface imbedded in ArcGIS 9.0 (ESRI, 2005) allowed the mapping parameters to be easily selected and modified.

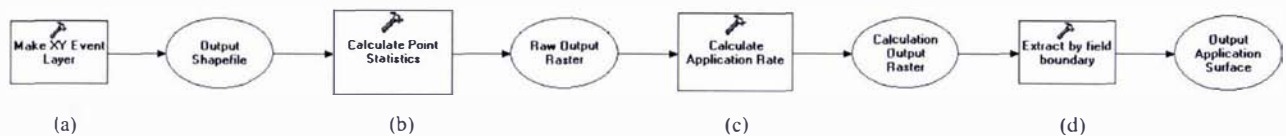


Figure 7.5. GIS model process to create fertiliser application surface ( $\text{kg ha}^{-1}$ ) from a raw XY event layer created from the field distribution calculator.

The tool performed four processes in order to create application surfaces (Figure 7.5):

1. Geographic quadrant location and mass data ( $x_{QUAD}$ ,  $y_{QUAD}$ ,  $m_{QUAD}$ ) were used to create an XY event layer (Figure 7.5a) within the GIS platform, the layer was projected in NZMG 1949 and displayed as a point shape file.

2. Using the point statistics function (Figure 7.5b) all point masses contained within a 0.5 x 0.5 m square were summed and converted to individual raster values ( $ras_1$ ) in grams. The point statistics function calculates statistics on point features that fall in the neighbourhood around each output raster cell (ESRI, 2005).
3. Equation 9 was performed using an inbuilt model calculator (Figure 7.5c) to convert each raster value ( $ras_1$ ) from fertiliser mass (g) contained within a 0.5 x 0.5 m quadrant to equivalent units ( $\text{kg ha}^{-1}$ ) in order to compare to proposed application rates. A new raster ( $ras_2$ ) was created.

$$ras_2 = ras_1 \times \frac{10000}{(0.5 \times 0.5)} / 1000 \quad (9)$$

4. Raster surfaces were clipped to the selected field boundary (Figure 7.5d) and application statistics (mean application rate, standard deviation and coefficient of variation) extracted from the application surface, the application surface (Figure 7.6) was also displayed for visual analysis.

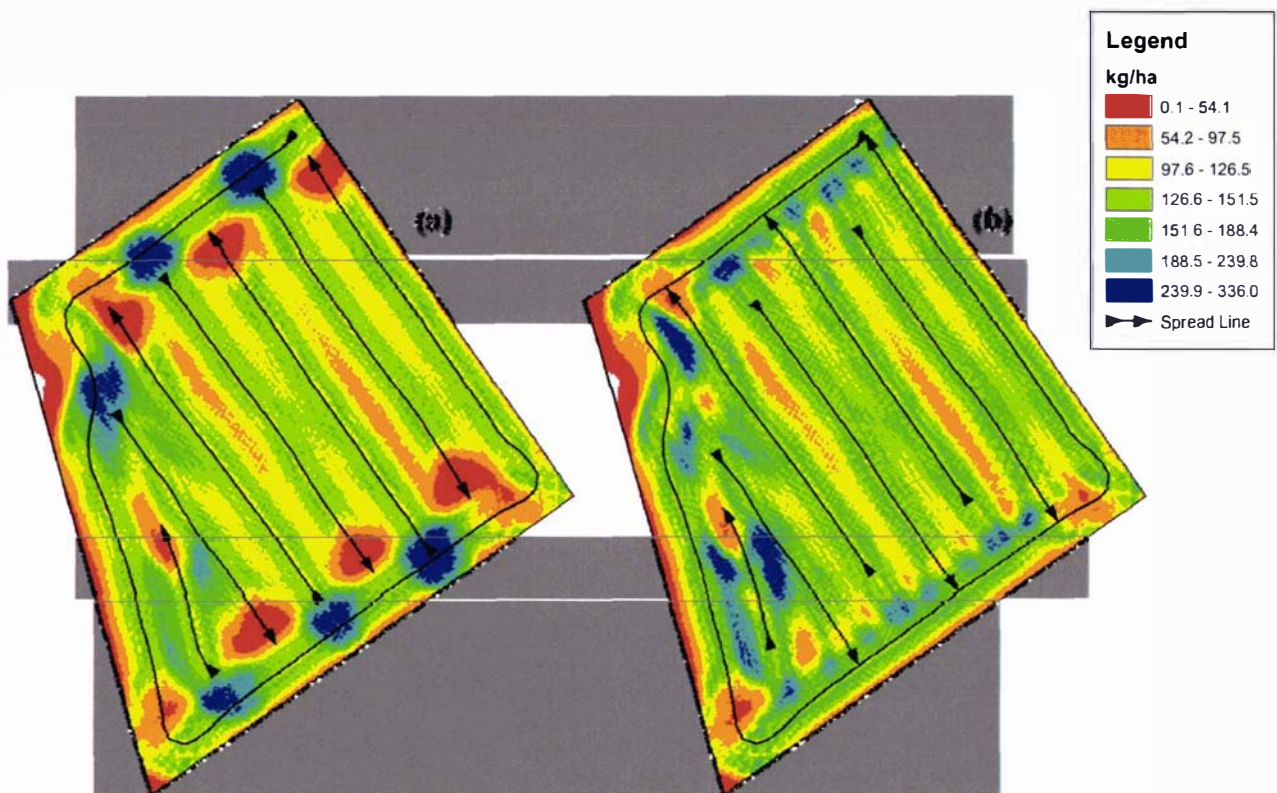
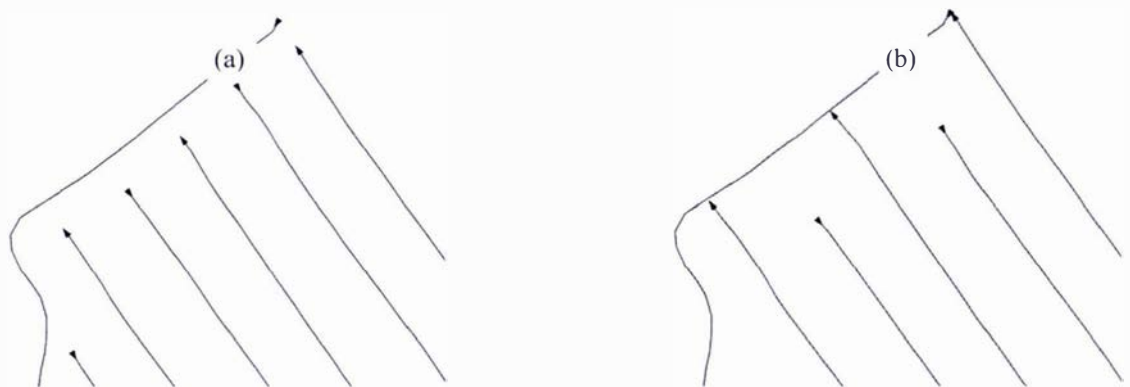


Figure 7.6. Fertiliser application surfaces created using measured machine parameters for original (a) and optimised (b) starting and stopping positions of the spreading vehicle during field application.

The initial point shapefile layer created contained 9,046,626 points. The file took 12 min 24 sec to process (3 min 34 sec per hectare) into an application map using the field application mapping tool. The method was constructed so it could be used on any GPS tracking data collected from a spreading vehicle providing a static spread pattern was available.

### 7.3. RESULTS AND DISCUSSION

The method was used to calculate fertiliser distribution accuracy on a 3.48 ha paddock of grazed permanent pasture; the target application rate was 125 kg ha<sup>-1</sup> of urea (46 % N). From extracted application statistics it was calculated that the actual average application rate was 128.0 kg ha<sup>-1</sup> (Std. Dev. = 49.3 kg ha<sup>-1</sup>), resulting in calculated field application CV of 38.5%. Figure 7.6a illustrates distinct areas where rate of application was over and under the target application value, particularly at the start and end of individual swath runs which caused the high field application CV (38.5%). The over and under application zones at the start and end of each swath were attributed to the starting and stopping positions of the spreading vehicle. Application was found too be starting and stopping too early which lead to large pattern overlap with the outside run at the start of application and no overlap with the outside run at the end of the application run.



**Figure 7.7. Fertiliser application start/stop positions for (a) Original GPS track data and (b) optimised start/stop positions to minimise significant over and under application at the start and end of individual swath runs.**

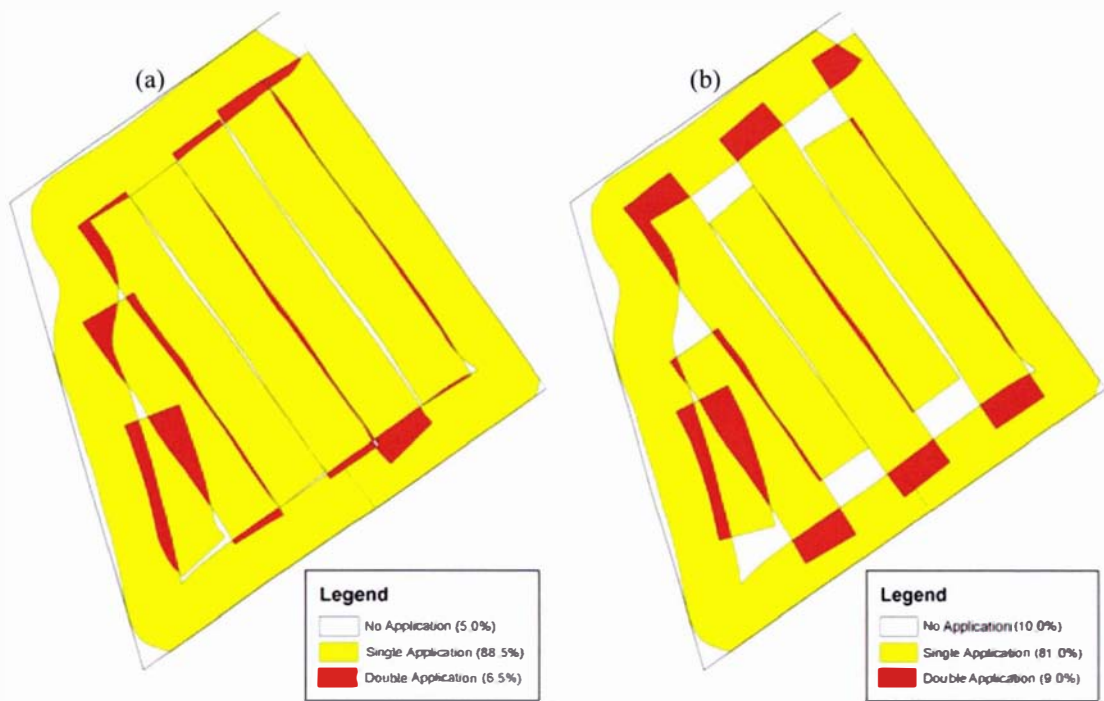
A modified driving track (Figure 7.7b) was created to see if the optimisation of start stop positions in the field could significantly reduce field application CV. Half the distance of the certified swath width of the spreader (12.5 m) was subtracted from the original application start positions and added to the original application stop positions in order to decrease the frequency of occurrence of over and under application.

Table 7.1 shows a comparison of application statistics for original (Figure 7.7a) and optimised (Figure 7.7b) starting and stopping positions of the spreading vehicle. Differences in average application rate were found to be negligible ( $0.3 \text{ kg ha}^{-1}$ ); however, there was a large reduction in calculated field application CV (13.5%) indicating a much more even distribution of nutrients. Lawrence and Yule (2006) concluded that a field application CV of less than 30% was required in order for a significant economic loss not occur on insensitively grazed pasture based systems when using nitrogen fertilisers. The optimisation of starting and stopping positions alone could achieve this reduction.

**Table 7.1. Comparison of application statistics for actual and optimised start/stop positions of a fertiliser spreader operating in a 3.48 ha field when attempting to apply  $125 \text{ kg ha}^{-1}$  of urea fertiliser.**

	Original	Optimised	Difference
Average ( $\text{kg ha}^{-1}$ )	128.0	128.3	0.3
Std. Dev. ( $\text{kg ha}^{-1}$ )	49.3	32.1	17.2
CV (%)	38.5%	25.0%	13.5%

The incorrect start and stop positions in the field are often through the incorrect use of the GPS guidance system. In this example both a “virtual road” and a “moving map” were used to assist the driver, however, because these systems did not allow for the large throw distance of fertiliser material behind the spreading vehicle it was not possible to see where the true start/stop points of the spreader should have been located. The output data from a “virtual road” can also often be misleading as a guide to where fertiliser has been applied. Figure 7.8a and 7.8b show what a “virtual road” map supplied post application would look like when original and optimised start/stop positions are used respectively. Clearly the original map (Figure 7.8a) shows that less nil application (5.0%) and double application (6.5%) zones were prevalent compared to when using the map derived from optimised start/stop positions (10.0% and 9.0% respectively) thus providing misleading results to the individual interpreting the maps. The use of the application modelling technique described in this technical note alleviates such issues as how to measure the true distribution of where fertiliser actually ends up in the field as well as providing tools to analyse the use of precision technologies.



**Figure 7.8. Zones of nil, single and double application as obtained using a “virtual road” maps created from (a) original and (b) optimised spreader application paths.**

#### 7.4. CONCLUSION

The method described in this chapter proves the value of creating accurate mapped fertiliser application surfaces. Using readily collected data an accurate measurement of field application variability could be calculated. The major conclusions were:

- The data and information obtained from using the created application surface model was beneficial in understanding potential problems with fertiliser application from centrifugal spreaders.
- Simple ‘virtual road’ GPS mapping software can be misleading to drivers and lead to uneven application zones especially at the start and end of swath runs.
- Significant reduction in field CV could be obtained by simply starting and stopping the spreading mechanism in the correct location in the field. This helped prevent major areas of over application that could lead to lodging of some crops.

Calculated surfaces could find many uses in an agricultural environment including: driver training, as it

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shows the effect of machine and human interaction on field application variation; agronomic analysis, to provide feedback for future field nutrient application; and economic analysis to calculate effectiveness of nutrient application strategies when combined with yield data.

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## CHAPTER 8

### AN ECONOMIC ANALYSIS OF FERTILISER APPLICATION ACCURACY ON NEW ZEALAND DAIRY FARMS

#### *Paper Reference*<sup>13</sup>

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Lawrence, H. G., I. J. Yule (2006). An economic analysis of fertiliser application accuracy on New Zealand dairy farms. *New Zealand Journal of Agricultural Research* XX: XXX–XXX. *Received 1 February 2007; (Under Revision).*

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**Abstract.** *Making efficient and economic use of fertiliser is an important factor in the future sustainability of New Zealand dairy systems. Science based decision support tools are currently available to calculate nutrient requirements for a farming system, however, the ability to implement a nutrient management plan using current spreading methods is less well known. This work assesses the ability to execute a nutrient management plan using both actual and optimised spreading data collected during field application. An economic analysis of production loss for two application methods was compared to theoretical nutrient application values where perfect spreading was assumed. An economic loss of \$66.18 ha<sup>-1</sup> was calculated when comparing the efficiency of using current spreading methods to obtain the required nutrient rate determined by nutrient management software. If a guidance and control system was used correctly to provide optimised field application the loss could be reduced to \$46.41 ha<sup>-1</sup>. An added cost to the per hectare charge out rate of between \$0.50 and \$2.47 ha<sup>-1</sup> would make the implementation of such a system economically viable for both the spreading contractor and dairy farming businesses. The implications of this work indicates that improving fertiliser application systems could have a significant agronomic and economic effect on New Zealand dairy farming businesses, if adopted.*

**Keywords.** *Fertiliser; economics; dairy farming; nutrient budget; soil.*

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<sup>13</sup> This chapter contains some changes to the published paper resulting from examiner emendations.

## **8.1. INTRODUCTION**

Fertiliser usage on New Zealand dairy farms is the largest single farm working expense making up over 18% of total farm working expenditure . Fertilisers are applied in order to achieve a nutrient status to maximise agronomic and economic return.

In dairy systems, fertilisers are typically applied by ground based broadcast spreaders, often by spreading contractors. The relationship between spreader operators and farmers is generally strong, and it is common practice for a farmer to trust the spreader operator to apply fertiliser to the correct farm, the correct paddock, and apply evenly at the correct rate and avoid waterways. This relationship has been identified as a limiting factor in the adoption by New Zealand dairy farmers requesting spreading vehicles equipped with Global Navigation Satellite Systems (GNSS) for guidance and traceability.

Accurate and precise nutrient application is a key part of nutrient management best practice; however, the economic value of evenness of spread or the financial consequences of significant unevenness of spreading is not well documented, especially when considering capital applications of phosphorous (P), potassium (K), and sulphur (S).

There is significant data and knowledge with respect to the modelling of nutrient requirements in pastoral dairy systems in New Zealand which has led to the development of the OVERSEER<sup>TM</sup> (AgResearch, 2006) nutrient budget and requirement software used to identify nutrients required to build or maintain a soil to or at its critical nutrient status (CNS). Both the Fertmark (NZFQC, 2002) and Spreadmark (NZFQC, 2006) quality assurance programs complement the OVERSEER<sup>TM</sup> (AgResearch, 2006) software by testing chemical fertilisers to ensure the quantities of nutrients declared are correct (Fertmark, NZFQC (2002)) and that they can be spread by a ground based broadcast spreader within specified levels of variation (Spreadmark, NZFQC (2006)). It is evident that only limited work on the evenness of fertiliser application in the field has been completed. Previous economic studies on investigations into the use of fertilisers have assumed perfect spreading with regard to fertiliser application rates achieved. Horrell et al. (1999) used the application variation within a transverse spreader test to assume field application rate variation, however, did not allow for the added effect of field variation. Field application variation is required to verify and provide feedback to a nutrient management plan, but, under current nutrient management practices this does not occur. An increase in the use of guidance and tracking systems used on commercial broadcast spreaders now provides a

means where field application analysis is possible, allowing economic performance to be evaluated with a higher degree of certainty.

### ***Objectives***

Whilst there is a considerable emphasis put on modelling the nutrient flows within pastoral farming systems, little account is taken of the accuracy of the field application process. This is a vital process in ensuring nutrient budgeting decisions are implemented in the field. The aim of this study was to evaluate the economic performance of all chemical fertilisers applied over a 12 month period within a dairy farming system when field performance of the spreader was computed. The specific objectives of the study were:

- Model the performance of nutrients applied on New Zealand dairy farms.
- Calculate field application variation for all chemical fertilisers applied within a dairy farming system over a 12 month period.
- Compare application measurement techniques to evaluate the effectiveness of implementing a nutrient management plan on farm.
- Calculate the economic efficiency of current spreading techniques for nitrogen, phosphorous, potassium and sulphur and compare to the theoretical assumption of perfectly uniform application and optimised field performance of a ground based broadcast spreader.
- Discuss the economics of implementing GNSS and spreader control systems from a farmer and contractor point of view.

## ***8.2. NUTRIENT USE ON NEW ZEALAND DAIRY FARMS***

### ***Soil Nutrient flows***

Each soil has differing potential to provide macro nutrients in plant available form; therefore, it is important to understand the effect of soil type on plant nutrient supply. Roberts & Morton (1999) separated New Zealand dairy farms into three major soil groups (ash/allophanic, sedimentary or pumice). The macro nutrients that are typically measured to assess soil fertility status for plant production on New Zealand dairy farms are phosphorous (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg), plus soil acidity (pH) (McLaren & Cameron, 1996).

Annual or biannual soil tests are typically carried out to assess change in soil fertility status. Fertiliser

applications are normally required to raise fertility status such that economic pasture production can occur particularly on high value land used for sheep and beef finishing or dairying. Table 8.1 refers to the CNS of different soils where near maximum plant production will occur.

The amount of nutrients required on a farm will depend on the stage of development. In the virgin state, most New Zealand soils are inherently deficient in P, S and to a lesser extent K and some trace elements for growing grass/legume based pastures. Large inputs of fertiliser (and often lime), together with the passage of time and recycling of nutrients through the grazing animal, are required to build up soil nutrient reserves and organic matter content.

As soil nutrient status increases so, too, pasture production increases rapidly and this is often referred to as the development phase. In the development phase, more fertiliser generally means more pasture, and capital (large) applications of fertiliser will be required for one or two years.

However, eventually, further increases in soil nutrient levels will result in only very small increase in production. At this stage, the optimum soil nutrient status has been achieved and the soil has reached the maintenance phase. In the maintenance phase, fertiliser is required simply to replace the yearly losses of nutrients from the farm. These losses are in livestock or their products leaving the farm, dung and urine deposited in yards, laneways, gateways, around troughs, shelter belts etc., plus the inevitable losses that occur in soils. The amount of "maintenance" fertiliser required equates to the total of the animal and soil losses.

**Table 8.1. Nutrient status for various soil types required to achieve near maximum pasture production on New Zealand dairy farms (adapted from Roberts & Morton (1999)).**

Soil Type	Olsen P	Quick Test K	Sulphate-S	Mg	pH
Ash	20 – 30	7 – 10	10 – 12	8 – 10	5.8 – 6.0
Sedimentary	20 – 30	7 – 10	10 – 12	8 – 10	5.8 – 6.0
Pumice	35 – 45	5 – 8	10 – 12	8 – 10	5.8 – 6.0
Peat	35 – 45	5 – 7	10 – 12	8 – 10	5.0 – 5.5

### ***Soil nutrient status***

Nutrient levels required to raise nutrient status to the CNS are given in Table 8.2 (Roberts & Morton, 1999). Nutrients required for maintenance in a dairy system are expressed in terms of kg ha<sup>-1</sup> per 100 kg MS produced (Table 8.3). This gives a good indication of nutrients removed from the system. Together,

development and maintenance nutrient levels provide an indication of the quantity and type of nutrients required to be added to the farming system in order to meet production targets.

**Table 8.2. Quantity of nutrients required to raise soil status to near optimum levels during the soil development period (adapted from Roberts & Morton (1999)).**

Soil Type	Kg P ha <sup>-1</sup> to raise Olsen P by 1 unit	Kg K ha <sup>-1</sup> to raise QT K by 1 unit	Kg S ha <sup>-1</sup> above maintenance	T Lime ha <sup>-1</sup> to raise pH by 0.1 unit*
Ash	11	60	25	1.5
Sedimentary	5	125	35	1.5
Pumice	7	45	45	1.5
Peat	-	-	-	0.7

\* Worked into soil

**Table 8.3. Quantity of nutrients required per 100 kg MS to maintain soil status at near optimum levels during the soil maintenance period (adapted from Roberts & Morton (1999)).**

Soil Type	Kg P ha <sup>-1</sup> per 100 kg MS	Kg K ha <sup>-1</sup> per 100 kg MS	Kg S ha <sup>-1</sup> per 100 kg MS	T Lime ha <sup>-1</sup> to raise pH by 0.1 unit
Ash	6	7.5	3	1.0
Sedimentary	5	5	4	1.0
Pumice	6	7.5	4	1.0
Peat	5	5	4	0.9

### **Nutrient planning**

In New Zealand pastoral agriculture nutrient management is often assisted by examining the nutrient balance for a paddock or farm by undertaking a nutrient budget. The nutrient budget aims to calculate the nutrients added to and removed from the farming system to determine whether the quantity of nutrients applied as fertiliser will maintain current soil status, if that status is appropriate. This concept was outlined by Cornforth & Sinclair (1984).

The current soil nutrient status is required for all nutrient balancing approaches, this is predominantly acquired through soil testing, "Best method" approaches include: dividing the farm into similar zones of soil, slope and grazing management history; selecting sampling transects for each area that avoid gateways, fences, trees, hedges and water troughs and collect multiple (15 or more) cores along each transect at the same time each year until a trend can be established (Roberts & Morton, 1999).

Once nutrient status of a soil is known, along with a variety of other information about the farm, a

nutrient budget can be performed. OVERSEER™ (AgResearch, 2006) is the nutrient budget model developed for New Zealand farming systems. This software provides average estimates of the fate of nutrients N, P, K, S, Mg, Ca and Na in kg ha year<sup>-1</sup> for different nutrient inputs and management practices (e.g., stocking rate, supplementary feed inputs) (Ledgard et al., 1999). This program uses elements of all three approaches described by Oenema et al. (2003).

### ***Nutrients use on farm***

Once nutrient levels for both the development (Table 8.2) and maintenance (Table 8.3) requirements are calculated, the quantity of nutrients (N, P, K, S) to be applied via fertiliser can be quantified. Typically, mineral fertilisers are applied in granular form by broadcast spreaders. The majority of N fertiliser applied on New Zealand dairy farms is in the form of urea (46, 0, 0, 0). Diammonium phosphate (DAP) (18, 20, 0, 1) is also used as a source of N as well as providing P and small amounts of S. Generally P is applied as superphosphate (0, 9, 0, 11) in either spring, autumn or both, a split application is recommended if application rates are greater than 100kgP ha<sup>-1</sup>. Potassium (K) can either be added to superphosphate in the form of potassium chloride (0, 0, 50, 0) or premixed with a range of other forms of N, P and S fertilisers. Because K moves through the soil solution rapidly, application should be split in high rainfall areas (>1500 mm yr<sup>-1</sup>). Application should also be split if application is greater than 50 kg K ha<sup>-1</sup>. Typically, S can be supplied as either sulphate S (The S in superphosphate and potash) or as elemental S (0, 0, 0, 100). Typically S requirements are met when applying either super phosphate or Potash fertilisers at maintenance P rates.

### ***Nutrient application assurance***

Most of the granular fertiliser applied on New Zealand dairy farms is by ground based broadcast spreaders. Two quality assurance programs operated in New Zealand (Fertmark and Spreadmark) aim to ensure accurate placement of nutrients on the land through this medium. Often, fertilisers are mixed together to achieve optimum nutrient application rates, however this can often hinder accurate application of individual nutrients if they do not have similar ballistic characteristics which can lead to nutrient segregation. Tissot et al. (1999) showed that the application rate of some components of mixed fertilisers can vary by more than 40% indicating nutrient segregation and therefore uneven application. Fertmark (NZFQC, 2002) have specific guidelines to follow when fertiliser mixes occur. These include the difference in size guide number (SGN) and uniformity index (UI) of mixed fertilisers being no greater than 20 units. Each fertiliser has a specific

SGN and UI value which indicates its particle size distribution. An SGN of between 250 and 300 units and a UI of between 20 and 60 units is the most desirable range for all fertilisers in order to obtain even spreading (NZFQC, 2006).

The Spreadmark program (NZFQC, 2006) operates in conjunction with the Fertmark program (NZFQC, 2002) to ensure that spreading vehicles operate at bout widths that perform under an acceptable level of variation ensuring uniform distribution of nutrients. However, neither of these programs incorporates traceability measures to identify field performance in order to provide feedback to a nutrient budget program.

### ***Effect of inaccurate nutrient application***

The inaccurate field application of nutrients can have a significant agronomic and economic impact on a dairy farming system through loss of yield, reduction in soil nutrient status or application beyond what is required to maintain the CNS of the soil (Table 8.1). A loss in yield expressed as kilograms of dry matter per hectare ( $\text{kg DM ha}^{-1}$ ) can be calculated when the fertiliser applied causes a direct response in pasture growth (e.g., N in the form of urea). The general pasture growth responses to fertiliser N in New Zealand pastoral systems is well documented (Ball & Field, 1982; Ball et al., 1978; Feyter et al., 1985; O'Conner, 1982) concluding that diminishing levels of pasture production occur with increased application of N fertiliser in single dressings. N fertiliser is best used as a tactical tool, when timing of application ensures that the pasture growth response coincides with expected pasture deficits. The ineffective use of nitrogen when soil N is not limiting pasture growth can result in loss of pasture growth and quality, costs associated with wastage through mechanical harvesting, lodged hay or silage crops, or increased maintenance applications.

In the application of P fertiliser a direct comparison to pasture yield response is harder to quantify because by definition at optimal soil P status there is no further significant pasture yield response to fertiliser P. In addition a significant decrease in Olsen P levels from under-application of P may not be seen for up to five years because of the large buffering capacity within the soil depending on soil P status. The nutrients K and S may move more rapidly through the soil profile (Roberts & Morton, 1999), therefore, moist soils do not have the same buffering capacity for K or S as they do for P. A model created by Metherell (1996) concluded that as long as P, K, and S values were maintained above the CNS (Table 8.1) then near maximum pasture production was possible. Applying less than the optimum P, K or S requirement could result in a reduction in soil nutrient status and therefore pasture production potential. However, in a trial over 12 pastoral sites around

New Zealand Sinclair et al. (1994) found that in the absence of P fertiliser, dry matter yields declined less rapidly than predicted suggesting an increased mineralisation of soil organic P and inorganic P buffering processes. The economics of applying P, K and S can only be expressed as either (a) the unnecessary cost of increasing soil nutrient status past the level required to achieve optimal pasture production, or (b) depleting the soil nutrient status through successive years of under application, in turn affecting pasture production levels.

An economic study on the effect of inaccurate spreading within New Zealand farming systems (Horrell et al., 1999) found that over all New Zealand based pastoral farming systems an economic loss of \$5 ha<sup>-1</sup> was significant. Using the transverse distribution CV from ground based broadcast spreaders as an indicator of the level of spread variation that would cause an economic loss, Horrell et al. (1999) concluded that on dairy farms, significant losses occurred at CV's greater than 40% when using nitrogen based fertilisers. For phosphate and sulphur based fertilisers an economic loss was expected when, over a 3-5 year period, the transverse CV of the spreader used was greater than 30%.

### **8.3. METHOD**

A method was developed to calculate within field variation of applied nutrients spread over a 12 month period on a Waikato dairy farm. The method used the transverse spread pattern and spreader tracking data to create fertiliser application surfaces from which application statistics could be extracted. Three application treatments were compared; actual GNSS track data from a broadcast spreader (1); simulation of an optimised GNSS track created within a Geographic Information System (GIS) (2); and the theoretical assumption of uniform nutrient application over the entire land area determined using nutrient management decision support software (3). The data from each treatment (1-3) was used to quantify the economic impact of nutrient application variation in terms of lost yield, surplus nutrient cost, and depletion of soil nutrient status on a whole farm basis.

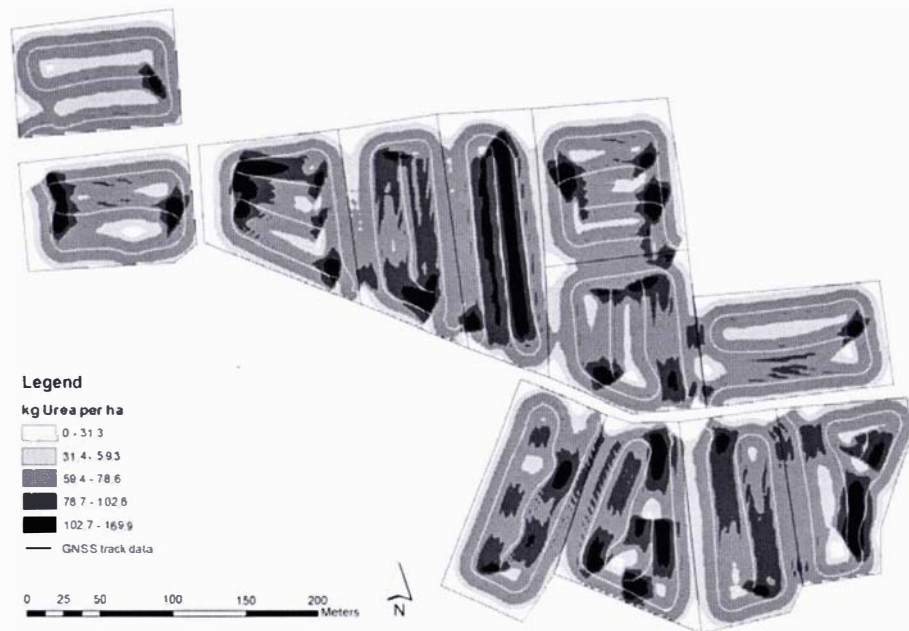
#### ***Farm***

The trial site used for this nutrient application study was in the Waikato region. The 107 ha property was under intensive dairy production and had predominantly flat topography. The property was subdivided into 79 paddocks between 0.46 and 8.01 ha (avg. = 1.35 ha). The property stocked 3.4 Friesian/Jersey cross cows per

hectare; the farm produced 1040 kg MS ha<sup>-1</sup> in 264 days on permanent ryegrass/white clover pastures. One hundred tonnes of maize silage were purchased off farm and used throughout the production season. The soil type on the property was Horotiu silt loam. Soil test data (Table 8.4) was obtained from the property and used to calculate nutrient requirements using Overseer™. Soil test targets given by Roberts & Morton (1999) (Table 8.1) indicated that all nutrient levels were at or above the optimum range to achieve near maximum pasture production.

**Table 8.4. Soil test data results from trial site situated on Horotiu silt loam in the Waikato region of New Zealand.**

Nutrient	Soil Test Result
Olsen P	32
Quick Test K	7.0
Organic S	11.0
Quick Test Ca	8.0
Quick Test Mg	20
Quick Test Na	7.0



**Figure 8.1. Fertiliser application surface for urea applied on 11.6 ha at a target application rate of 65 kg ha<sup>-1</sup>.**

Calculated mean application rate for the applied area was 68.6 kg ha<sup>-1</sup> (sd = 23.2 kg ha<sup>-1</sup>) indicating field application variation of 33.8%.

### ***Spreading Equipment***

The spreader used in this study was a truck mounted Bredal spreader, the spreader was Spreadmark (NZFQC, 2006) certified and was registered to spread at a swath width of 14 m for lime (23% transverse CV), 26 m for urea (15% transverse CV) and 32.5m for superphosphate (25% transverse CV). However, during field application a swath width of 26 m was used for the application of superphosphate (12% transverse CV). Under Spreadmark regulations (NZFQC, 2006) the transverse CV must be less than 15% for nitrogen based fertilisers and 25% for all others. Tracking data was collected from the spreader using a GPS system with an absolute accuracy of less than 10 cm.

### ***Nutrient analysis***

A nutrient budget was created in OVERSEER™ (AgResearch, 2006) on a whole farm basis. The total N, P, K, S, Ca, Mg and Lime maintenance requirements based on soil test data (Table 8.4) and information obtained from the trial farm was calculated. The budget calculated the total nutrients required to meet soil maintenance requirements as well as give a prediction of relative yield based on applied nutrients.

### ***Application variation model***

A GIS method developed by Lawrence & Yule (2006) allows the variability within field application of fertiliser to be calculated. The model used spread pattern and GNSS track data from the broadcast spreader to predict actual field application rates at a spatial resolution of 0.5 m. An application surface showing the variability of nutrient dispersion both at paddock and farm level was also created (Figure 8.1). Statistics obtained from individual paddock application surfaces were used to evaluate the economic use of N, P, K and S and the effect on soil nutrient status.

**Table 8.5. Typical on-ground nutrient costs when applied as granular fertiliser from a broadcast spreader as calculated using Overseer (AgResearch, 2006).**

Nutrient	On Ground Cost (\$ kg <sup>-1</sup> )
N	1.20
P	2.10
K	0.90
S	0.30
Ca	0.15
Mg	0.60
Na	0.65

### ***Economic analysis***

The economic response of applying different types of nutrients were quantified into three categories: lost yield; surplus nutrient cost; and depletion of soil nutrient status.

Yield loss was based on the difference in pasture quantity grown between the maintenance nutrient application rate calculated from OVERSEER™ (AgResearch, 2006) (3) and the measured application rate using the GIS model described (1). The cost of producing pasture is governed by land value and pasture production levels, Penno et al. (1996) gives pastures values ranging from \$0.07 kg DM<sup>-1</sup> to \$0.20 kg DM<sup>-1</sup> depending on land value and pasture production levels on New Zealand dairy farms. The trial site had recorded average pasture production levels of 15200 kg DM ha yr<sup>-1</sup> whilst average national dairy land values were \$18,666 ha<sup>-1</sup> (LIC, 2006). Using this base information it was calculated the value of the pasture from this land was \$0.176 kg DM<sup>-1</sup>.

The predicted yield response to nitrogen at different application rates given by Ball & Field (1982) was used to calculate the economic cost of inaccurate application of nitrogen based fertilisers. The response function used was normalised for New Zealand pasture characteristics, seasons and growth management by using the relative yield over a number of years from several sample sites, this enabled the same response function to be used throughout a whole season (Figure 8.2).

For P, K and S based fertilisers the surplus nutrient cost was calculated as the total volume of nutrient applied above maintenance levels as calculated in the nutrient management plan. When nutrients were under applied and soil is at its critical nutrient status a potential reduction of soil nutrient status could be calculated in Overseer™ (AgResearch, 2006). Typical on ground costs for individual nutrients are given in Table 8.5 and these values were used to calculate both the surplus nutrient cost and soil depletion cost of P, K and S.

## ***8.4. RESULTS AND DISCUSSION***

### ***Application accuracy analysis***

Nutrients were applied at maintenance rates estimated from decision support software. Commonly, there is variation around target application rates, variation levels were calculated for both actual and optimised application events. These were compared to the theoretical nutrient analysis as calculated from the nutrient management software in order to analyse the accuracy of field application and secondly to calculate the

economic effect of field application techniques.

*Optimised nutrient analysis* - Based on current soil test results (Table 8.4), Overseer™ (AgResearch, 2006) was used to calculate the nutrients required from fertiliser on an annual basis (Table 8.6). Because the soil was already at its CNS no capital fertiliser was required. The model predicted that applying the described mix of nutrients should achieve near maximum pasture production levels (92%). Optimised pasture production levels are found between 90 and 95% of maximum (Roberts & Morton, 1999).

**Table 8.6. Maintenance nutrients required in order to maintain soil status at current optimal levels of the Waikato trial site.**

	P	K	S	Ca	Mg	Na	Lime	Overall yield (%)
Nutrients Required (kg ha yr <sup>-1</sup> )	47	64	8	102	25	36	220	-
Predicted relative yield (%)	99	99	92	100	100	100	-	92

Using a fertiliser optimisation calculator created in VB.net (Microsoft Corporation, 2002) the required nutrients (Table 8.6) were converted into fertiliser form. Using a “base” fertiliser mix of superphosphate and potassium chloride, plus urea and lime used tactically throughout the year was optimum (Table 8.7). All nutrients except S were supplied at optimum levels. However, when P is supplied in the form of super phosphate, S requirements are usually also met or exceeded (Roberts & Morton, 1999). The over-supply of S, in this form, did not have high leaching potential as the soils were allaphanic with high anion exchange capacity. The rate of lime required was dependent on the amount of N based fertiliser used as well as pasture grown and nitrate leached. For this trial an average rate of 150 kg N ha yr<sup>-1</sup> was used for budgeting purposes. This N application rate together with pasture growth, N mineralisation and leaching had a slight acidifying effect on the soil, which would be negated by a maintenance lime application of 220 kg ha yr<sup>-1</sup>. In total 1201 kg ha<sup>-1</sup> of fertiliser were required to be applied in order to achieve near maximum production levels. This had an estimated cost of \$317 ha yr<sup>-1</sup> (\$33,919 yr<sup>-1</sup>) excluding spreading costs (Table 8.7).

**Table 8.7. Optimised fertiliser requirement (kg ha<sup>-1</sup>) and cost (\$ ha<sup>-1</sup>) in order to maintain soil status at current optimal levels on a 107 ha Waikato dairy farm over a 12 month period as calculated by a nutrient budget.**

	\$ T <sup>-1</sup>	Kg ha <sup>-1</sup>	\$ ha <sup>-1</sup>	Individual Nutrients (kg ha <sup>-1</sup> )				
				N	P	K	S	Lime
<i>Base Fertiliser</i>								
Superphosphate	\$191	505	\$96	-	47	-	55	-
+Potassium Chloride	\$425	128	\$54	-	-	64	-	-
<i>Nitrogen</i>								
Urea	\$500	326	\$163	150	-	-	-	-
<i>Lime</i>								
Ag Lime (91% neutralising)	\$17	242	\$4	-	-	-	-	220
Total		1201	\$317	150	47	64	55	220
<b>Required Optimum</b>				150	47	64	8	220
Difference				0	0	0	+47	0

In order to apply the required fertiliser nutrients by best practice it was calculated that eight applications would be required throughout the year (Table 8.7). A split base fertiliser application (7.4: 10.1: 8.7) in spring and autumn was necessary because of the large K application required (64 kg K ha<sup>-1</sup>). Roberts & Morton (1999) advise splitting applications of greater than 50 kg K ha<sup>-1</sup> allows less K uptake by the plant resulting in fewer losses in urine through the animal, reducing the opportunity for K leaching. A single lime application was required; this could be applied at any stage throughout the season. Five split applications of urea (46% N) were used (30 kg N ha<sup>-1</sup> per application); this gave a normalised N response of 15.57 kg DM kg N<sup>-1</sup> over a 12 month period which is near optimum using the response function given by Ball & Field (1982).

Average national spreading costs were estimated to be \$10.24 ha<sup>-1</sup> per application (Burt, 2004). Therefore, total spreading costs for the eight applications on the 107 ha property were estimated to be \$8765. Total fertiliser related costs over a 12 month period were therefore \$42,684 (\$398 ha<sup>-1</sup>).

*Actual nutrient application* - Data collected from spreading events of superphosphate, lime and urea from the trial property were analysed using the GIS surface application model described by Lawrence & Yule (2006). The GIS model extracted application statistics for each application event. In total there were 183 individual application events used as the basis to calculate current levels of field application variation.

Over all application events field CV ranged between 23.5 and 80.0% when all products were included.

On average the spreading of urea produced the lowest field CV on the trial property (34.9%) followed by superphosphate (35.6%) and lime (54.3%). One of the largest contributions to field CV was the variation present in the transverse pattern of the spreader; these were 12, 15 and 23 % for superphosphate, urea and lime respectively. Other influences on field CV included paddock size, paddock shape, topography, GPS precision, swath variance and other driver related factors. Field application variation due to these error sources was between 8.5 and 57.0% ( $\bar{\chi} = 20.4\%$ ), however, urea had statistically lower field application errors (19.9%) than superphosphate (23.6%) and lime (31.3%) respectively. Superphosphate applications had the smallest average increase above allowable transverse CV limits (10.6%) as the spreading vehicle used a 26 m swath rather than the allowable 32.5 m swath during spreading operations. Target application rates (kg ha<sup>-1</sup>) were within acceptable limits for urea ( $\pm 6.8\%$ ) and lime ( $\pm 9.3\%$ ) applications, however, target application rates of superphosphate were not as well achieved ( $\pm 26.8\%$ ).

**Table 8.8. Calculated application statistics for a fertiliser program to apply maintenance nutrient requirements plus 150 kg N ha<sup>-1</sup> over 8 application dressings in a 12 month period.**

Fertiliser	No. Apps.	Avg. Rate per app. (kg ha <sup>-1</sup> )	Std. Dev. per app. (kg ha <sup>-1</sup> )	Avg. field CV per app (%).
Super phosphate	2	316.5	95.0	35.6 %
Urea	5	65.2	22.7	34.9 %
Lime (91% neutralising)	1	241.8	131.3	54.3 %

Field application statistics were used to calculate the accuracy of executing the defined fertiliser program (Table 8.7). Table 8.8 shows statistical data for the application events required to execute the defined nutrient requirement program. It was assumed for economic calculations that a normal distribution of application variation statistics would be achieved for each product in further spreading operations.

*Optimised nutrient application* - An optimised driving pattern was created in ArcGIS 9.1 (ESRI, 2005) for a 26 and 14 m swath pattern in order to create optimised application maps for urea (26 m), superphosphate (26 m) and lime (14 m) respectively. The same transverse distribution as used when calculating actual application variation was used when processing the data. It was assumed that the same driving path would be followed for duplicate application events of both super phosphate and urea. Using this method it was found that average application rates for urea were within  $\pm 4.1\%$ ,  $\pm 9.6\%$  for superphosphate and  $\pm 20.3\%$  for lime.

Standard deviation in application rates was less than that obtained using GNSS collected data. This reduced the calculated field CV over all applications. Field CV for all applications of urea, superphosphate and lime were 27.5%, 33.2% and 50.4% respectively using an optimised driving path.

**Table 8.9. Area percentage of fertiliser within  $\pm 10\%$  of target application rate for actual and optimised driving patterns for base and urea fertiliser used on a 107 ha Waikato dairy farm over a 12 month period assuming no longitudinal variation in application.**

	+/-10% target rate	Over applied	Under applied
<i>Actual Application</i>			
Base fertiliser	26.8%	43.6%	29.6%
Urea	74.8%	17.0%	8.2%
<i>Optimised application</i>			
Base fertiliser	36.4%	33.6%	30.0%
Urea	85.8%	2.1%	12.1%
<i>Difference</i>			
Actual - Optimised (Base fertiliser)	-9.6%	10.0%	-0.4%
Actual - Optimised (Urea)	-11.0%	14.9%	-3.9%

*Summary of application measurement methods* - Considerable variation in application rate from the defined target rates was calculated when using both GNSS track data and an optimised driving pattern. Field CV in all applied products was reduced when an optimal driving pattern was used instead of collected GNSS track data, however, only the difference in urea application was statistically significant ( $p < 0.0001$ ). The mean field CV was reduced by 5.3%, 2.4% and 3.9% for urea, superphosphate and lime respectively. Over the entire 107 ha there was found to be a 9.6% increase in fertiliser being applied within  $\pm 10\%$  of the desired application rate for base fertiliser and an 11% increase for urea between actual and optimised driving patterns (Table 8.9). For both the base fertiliser and urea applications there was a slight increase in areas that were under applied but a significant reduction in areas that were over applied between using actual and optimised driving patterns (Table 8.9). The application statistics calculated for both the actual and optimised application methods were used to perform an economic analysis of the fertiliser applied on farm. These were compared to the theoretical quantity of nutrients applied calculated using nutrient requirement decision support software.

### ***Economic Analysis***

An economic analysis at varying levels of field application variation was performed based on nutrients required to maintain current soil fertility levels. The application of a formulated base fertiliser containing P, K

and S was economically evaluated based on the surplus nutrient cost and depletion of soil status. N fertiliser, applied as urea, was economically evaluated as the quantity of lost yield between the theoretical N response rate (15.57 kg DM kg N<sup>-1</sup>) and the actual N response calculated for individual application surfaces. The application of lime was not considered when calculating fertiliser economics.

**Table 8.10. Total quantity and value of Phosphorus (P), Potassium (K) and Sulphur (S) applied over optimum maintenance levels on a 107 ha Waikato dairy farm over a 12 month period.**

	P	K	S
<i>Actual Application</i>			
Total over applied	1075.3	1465.1	1259.4
Value of over applied nutrients	\$2,258	\$1,319	\$378
<i>Optimised application</i>			
Total over applied	828.3	1128.6	970.1
Value of over applied nutrients	\$1,739	\$1,016	\$291
<i>Difference</i>			
Actual - Optimised (Quantity)	247.0	336.5	289.3
Actual - Optimised (Value)	\$518.7	\$302.9	\$86.8

**Table 8.11. Total quantity of Phosphorus (P), Potassium (K) and Sulphur (S) applied under optimum maintenance levels and the respective reduction in soil nutrient status on a 107 ha Waikato dairy farm over a 12 month period.**

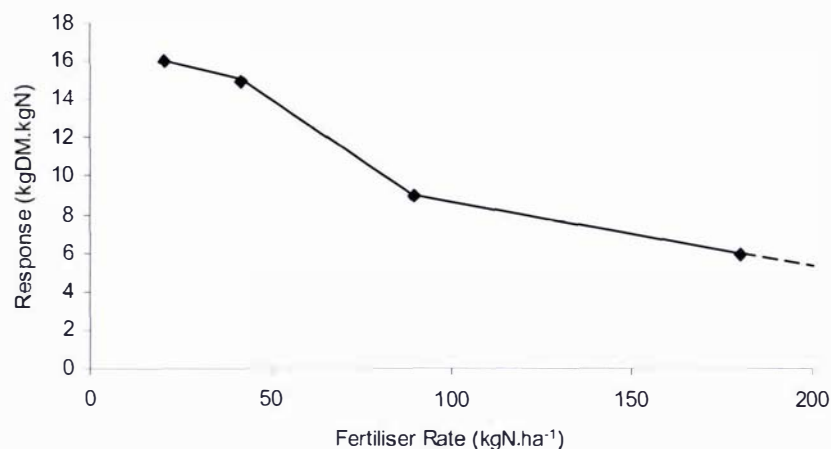
	P	K	S
<i>Actual application</i>			
Total under applied	257.4	350.7	301.4
Reduction in soil test status*	-0.7	-0.2	-0.4
<i>Optimised application</i>			
Total under applied	261.2	355.9	305.9
Reduction in soil test status*	-0.7	-0.2	-0.4
<i>Difference</i>			
Actual - Optimised (Quantity)	-3.8	-5.2	-4.5
Actual - Optimised (Soil status)	0.0	0.0	0.0

\* P(Olsen P), K(Quick test K), S(Sulphate S)

*Base fertiliser economics* - Considerable over and under application (> ±10% of target rate) of base fertiliser (super phosphate + potassium chloride) was calculated using actual application measurement techniques. Nutrients were over-applied on 46.7 ha of the total area. Over application of P had the largest economic impact with 1075 kg being applied above optimal levels (Table 8.10). Overall, 3800 kg of P, K and S were over applied at an economic loss of \$3955 (\$36.96 ha<sup>-1</sup>) over the 107 ha property. Roberts & Morton (1999) state that increasing nutrient status beyond the critical nutrient level is wasteful. Using an optimised driving path the over-application of P, K and S could be significantly reduced, only 2927 kg of nutrients were

over applied, a total saving of \$908.40 ( $\$8.49 \text{ ha}^{-1}$ ) over the 107 ha property annually.

The economic value of under application of nutrients was harder to quantify due to the ability of soils to supply nutrients from non fertiliser sources, e.g., mineralisation of clay minerals, organic matter etc. (Roberts & Morton, 1999). Overall, 31 ha (29.6%) of base fertiliser was under applied when using the actual driving pattern and there was no significant reduction in area under-applied when using an optimised driving pattern ( $p>0.05$ ). Sinclair et al. (1994) indicated that reduction in P application rates would not have an effect on pasture production for several years. However, it was calculated from Overseer (AgResearch, 2006) that when using both actual and optimised driving patterns there would be an average reduction in soil nutrient status in under-applied areas of 0.7 units for Olsen P, 0.2 units for quick test K and 0.4 units for sulphate S (Table 8.11). In order to raise fertility status back to near optimum levels in subsequent applications for these areas it was calculated that  $7.7 \text{ kg P ha}^{-1}$ ,  $12 \text{ kg K ha}^{-1}$  and  $10 \text{ kg S ha}^{-1}$  would be necessary above maintenance requirements. This is an economic value of  $\$29.97 \text{ ha}^{-1}$ ,  $\$929$  for the 31ha under applied area. Because zones of under application were spread throughout the 107 ha, a variable rate application system would be required to increase application rates on these zones, but with current spreader performance levels it would be difficult to achieve this. It is also important to note that animal transfer of these nutrients may reduce the size of this economic effect.



**Figure 8.2. Response to nitrogen as effected by pasture characteristics, season and growth management (Adapted from P. B. Ball & Field, 1982)**

*Nitrogen fertiliser* - The economic response to N fertiliser was calculated as the difference in pasture dry matter yield between theoretical and actual N responses. In all calculations  $150 \text{ kg N ha}^{-1}$  ( $326 \text{ kg Urea ha}^{-1}$ ) in five split applications was used. The theoretical N response was  $15.57 \text{ kg DM kgN}^{-1}$ . Because of variation

in nitrogen application rate deviations were expressed in N response for actual and optimised driving patterns. Using actual driving patterns N response was reduced to 14.46 kg DM kg N<sup>-1</sup> applied. However this was increased to 14.89 kg DM kg N<sup>-1</sup> applied when using an optimised driving path. A 166 kg DM ha<sup>-1</sup> reduction in pasture dry matter production was calculated between theoretical and actual N responses, this was reduced to 102 kg DM ha<sup>-1</sup> when using an optimised driving path, a 64 kg DM ha<sup>-1</sup> difference (Table 8.12). Although this difference only represents 0.004% of total annual production a significant economic loss was calculated. At a pasture value of \$0.176 kg DM the reduction in pasture dry matter yield represents an economic loss of \$29.22 ha<sup>-1</sup> when using actual driving data, and a loss of \$17.95 ha<sup>-1</sup> when using optimised driving data, an improvement of \$11.26 ha<sup>-1</sup>. Over the 12 month period it would be expected at current performance levels that production losses due to inaccurate nitrogen application would be \$3127 on the 107 ha property (\$29.22 ha<sup>-1</sup>).

**Table 8.12. Nitrogen response and respective production and economic values for theoretical, actual and optimised driving patterns using 150 kg N ha<sup>-1</sup> split into five equal applications over a 12 month on a 107 ha Waikato dairy farm.**

	Avg. N CV	Avg. N response*	Production gain (kg DM ha <sup>-1</sup> )	Production Value (\$ ha <sup>-1</sup> )**
Theoretical N applied	0%	15.57	2336	\$411.14
Actual N applied	34.9%	14.46	2170	\$381.92
Optimised N applied	27.5%	14.89	2234	\$393.18
Difference				
Theoretical - Actual	-	1.11	166	\$29.22
Theoretical - Optimised	-	0.68	102	\$17.95
Actual - Optimised	-	-0.43	-64	-\$11.26

\* Calculated from Ball & Field (1982)  
 \*\* Pasture value based on \$0.176 kg DM

*Economic Summary* - Total economic losses calculated over a 12 month period from actual application data for both base and nitrogen fertilisers was \$66.18 ha<sup>-1</sup>, well above the level deemed significant from the survey undertaken by Horrell et al. (1999). The total cost of all applied fertiliser was \$33,919 yr<sup>-1</sup> (317 ha<sup>-1</sup>) and spreading costs were \$8,765 yr<sup>-1</sup> (82 ha<sup>-1</sup>) for the 107 ha dairy unit. Losses totalled \$7082 (66.19 ha<sup>-1</sup>), 16.6% of the total input cost of fertiliser operations. When an optimised driving pattern was used total losses totalled only \$4967 (\$46.42 ha<sup>-1</sup>), a \$2115 (\$19.77 ha<sup>-1</sup>) reduction or 11.6% of annual fertiliser and spreading costs. Optimised spreading could occur with the correct use of GNSS guidance and application control systems. From this economic study the break even cost to a dairy farming business of implementing the

technology could be calculated, this was \$2.47 ha<sup>-1</sup> above standard spreading costs (\$10.40 ha<sup>-1</sup>). A break even analysis (Table 8.13) was performed based on the assumption a spreading vehicle spreads 7,000 ha of fertiliser annually and the GNSS and control system costs between \$5,000 and \$30,000 to implement with a useful life of between two and twelve years. The break even charge out rate (\$ ha<sup>-1</sup>) above the \$10.40 ha<sup>-1</sup> standard rate to cover the cost of depreciation was calculated to be always less than the break even charge out rate in order for farmers to implement the technology (\$2.47 ha<sup>-1</sup>). The capital cost of the equipment would have to be greater than \$139,500 (depreciated over 8 years) in order for the charge out rate to be greater than the \$2.47 ha<sup>-1</sup> where it would be uneconomic for farmers to use the implemented technology. Depending on implementation costs and the useful life of the technology an added charge out rate of between \$0.06 ha<sup>-1</sup> and \$2.14 ha<sup>-1</sup> above current spreading charges would be required to be economic for a spreading contractor to implement (Table 8.13).

**Table 8.13. Added spreader contractor charge out rate (\$ ha<sup>-1</sup>) required above the current rate (\$10.40 ha<sup>-1</sup>) in order for a spreading contractor to break even when implementing a GNSS guidance and spreader control system of various value and over different time periods for a machine spreading 7000 ha yr<sup>-1</sup>.**

		Implementation cost (\$)					
		\$5,000	\$10,000	\$15,000	\$20,000	\$25,000	\$30,000
Useful life (yr)	2	\$0.36	\$0.71	\$1.07	\$1.43	\$1.79	\$2.14
	4	\$0.18	\$0.36	\$0.54	\$0.71	\$0.89	\$1.07
	6	\$0.12	\$0.24	\$0.36	\$0.48	\$0.60	\$0.71
	8	\$0.09	\$0.18	\$0.27	\$0.36	\$0.45	\$0.54
	10	\$0.07	\$0.14	\$0.21	\$0.29	\$0.36	\$0.43
	12	\$0.06	\$0.12	\$0.18	\$0.24	\$0.30	\$0.36

## 8.5. CONCLUSION

Fertiliser inputs are the single largest farm expenditure item annually. Improved utilisation of current applied quantities can have a significantly positive impact on the economic return of a farming business. A review of literature identified sound resources to base nutrient management plans on, however, little information on the ability of spreading vehicles to implement the required rates of application accurately. This work evaluated the current position of fertiliser utilisation and economic return, compared this to what is theoretically assumed from a maintenance nutrient requirement assessment and what could be achieved using optimised application techniques. The dairy system examined showed significant economic losses (\$66.18 ha<sup>-1</sup>) when using current spreading methods. Although it is impractical to assume that fertiliser could be applied

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at theoretical levels due to inherent variability in all facets of the fertiliser application process, significant improvements could be made. Optimised driving paths, potentially achievable when using GNSS guidance and control systems, could reduce the economic loss by \$19.77 ha<sup>-1</sup>, a 28.2% improvement annually. Implementation costs of the technology showed that an economic advantage could be obtained for both spreading contractors and farmers if the added cost above current spreading charges was between \$0.50 and \$2.47 ha<sup>-1</sup>. In order for advanced fertiliser application technologies to be adopted within New Zealand dairy systems, sound fiscal data was required. This work shows how small incremental changes to the fertiliser application system can have significant economic and agronomic returns to farmers as well as increasing revenue streams of spreading contractors indicating that adoption of technology in fertiliser application systems should be encouraged.

## CHAPTER 9

# CONCLUSION

### **9.1. BACKGROUND**

The application of fertiliser from ground based spreading vehicles is extensive throughout New Zealand. However, the accuracy of applying fertilisers using this mechanism can be highly variable. Typical causes of inaccurate application include product variability, machine design and operator behaviour. Currently, two quality assurance programs are used in New Zealand to control parameters associated with product variability (Fertmark (NZFQC, 2002)) and machine design through pattern testing (Spreadmark (NZFQC, 2006)). The philosophy of this thesis was to firstly examine the procedures to test and calibrate ground based fertiliser application vehicles; factors including determining working widths for field application and method design were examined. Secondly, operator behaviour during field application was measured and evaluated using both current and precision application techniques, new methods were defined that could be incorporated into future quality assurance programs. Finally, economic and agronomic case studies are presented in order to define the feasibility of incorporating precision agricultural technologies within current fertiliser spreading techniques.

### **9.2. SUMMARY**

#### ***Chapters 2 – 4***

Experiments were conducted to evaluate the use of using transverse spreader tests to explain spreader performance. Experiment 1 (Chapter 2) evaluated different testing programs used throughout the world. Major differences between test methodologies in terms of predicting operator working width were identified. It was concluded that direct comparison between methods should be avoided and if comparison was required between two spreaders, the same test methodology should be used. The concentration of trays around the centre of the distribution pattern ( $\pm 5$  m) was found to have a significant effect on the calculation of certifiable swath width; trays beyond  $\pm 5$  m of the centre line tray had less effect. It was concluded that it would be practical to simplify testing procedures by reducing the number of trays beyond  $\pm 5$  m from the path of the spreader whilst maintaining a tight concentration of trays around the centre of the distribution.

Chapter 3 further investigated trial data collected in Chapter 2. Initially the data set was interrogated to see if a near neighbour effect existed when trays are laid out edge to edge in the longitudinal direction. There was found to be no near neighbour effect at application rates of 80 and 100 kg ha<sup>-1</sup>, however, at 150 kg ha<sup>-1</sup> some periodicity was seen in adjacent trays. To avoid this effecting fertiliser spreader tests it is concluded that transverse rows of trays should be placed as far apart as feasibly possible. A statistical check on using different international test methods was also performed in this chapter. International spreader test methods were reconstructed from each 1400 tray application test. The most accurate test in terms of predicting spreader bout width was found to be the ACCU-Spread test which contained two rows of trays 50 m apart in the longitudinal direction; this test gave the highest probability of calculating the correct bout width for the spreading vehicle. The ES (Europe) test method was next best, followed by the ISO(i) (World), ISO(ii) (World) and Spreadmark (NZ) tests which were all found to be comparable to one another. The ASAE (USA) method performed the poorest; this was due to the wide spacing of trays in the transverse direction. It was concluded from this work that better accuracy is obtained by having multiple rows and multiple passes of the truck before the fertiliser mass is weighed.

After a review of major testing programs used throughout the world it was found that many testing programs failed to evaluate particle characteristic parameters. Particle characteristic data was seen as important for understanding the spreadability of products as well as measuring chemical distributions of mixed fertilisers. An image processing method was developed that captured images of fertiliser contained in collection trays during spreader testing (Chapter 4). Regression analysis identified a significantly positive relationship ( $R^2 = 0.991$ ) between particle mass and Projected 2D particle area on calibration images. The developed equation was used to predict total particle mass on images captured in the field. A strong relationship ( $R^2 = 0.988$ ) between measured and predicted particle mass was obtained. The method was also found to be a good predictor of size guide number (SGN) and uniformity index (UI) values for individual fertiliser mixes. The method was able to show that there was a significant increase in UI values between pre and post spreading analysis in all tests indicating particle breakage from the spreading mechanism. Being able to measure particle characteristics post spreading was seen as a major benefit of the image processing system as usually only pre spreading analysis is performed.

The analysis from all results from transverse testing experiments found that significant variability exists

in all facets of fertiliser application. However, the two quality assurance programs operated in New Zealand, Fertmark (NZFQC, 2002) and Spreadmark (NZFQC, 2006) were acceptable when compared to international standards. The two programs provided good control of fertiliser manufacture and spreader performance, however, the ability to manage fertiliser application in the field is less well defined by all testing programs. This was seen as a major weakness in the effectiveness of using such measures to assess variability levels. Chapters 5 – 8 addressed these issues.

### ***Chapters 5 – 8***

The assessment of field fertiliser application is difficult due to the large area that requires analysing. Chapters 5 – 8 aimed to firstly develop methodologies that could be used in the assessment of field application, then to measure current performance levels, and finally to quantify the agronomic and economic losses achieved through poor nutrient application and address whether the adoption of precision agricultural technologies is viable for fertiliser application systems in New Zealand.

Three methods were developed to calculate field application variation over the course of the study. A basic method (Chapter 5) showing areas of nil, single and multiple application was initially developed, this method used the desired swath width and vehicle position in the field. Results using this method showed that between 5% & 20%, 70% & 90% and 0 & 20% of a tested paddock received nil, single and multiple levels of the target application rate respectively. This method correctly defined areas of over and under application. However, it was inadequate in expressing variation in terms of field CV. An improvement on this method used the transverse spread pattern represented as polygons between each recorded geographic location, the application rate could be sampled at 0.5 m intervals across the field, and this allowed a mean and standard deviation to be calculated which could be used to measure field CV (Chapter 5 and 6). Chapter 5 evaluated the effect of driving method, driving accuracy, paddock shape and spreader pattern on field application variation over four paddocks. There was found to be far greater variation in field CV than that measured from a single transverse test. The Spreading vehicle used had a transverse spread variation of less than 15%, however, the average field CV calculated was 33.1% indicating that 18.1% of the variation was due to driving accuracy, driving method or paddock shape. The field CV could be reduced to less than 30% in all scenarios when using either an up and down or round and round driving method where perfect pass to pass accuracy was used. Chapter 6 examined a much larger data set, 102 paddocks; average field variation calculated over

all paddocks was 37.9%. Irregular paddock shape was found to have higher application variation (40.8 %) compared to regular shaped paddocks (35.9 %). The method presented in Chapters 5 and 6 was useful for machines fitted with flow control systems where constant flow could be assumed, however, the method did not take into consideration variability in flow rate, disc speed or forward vehicle speed. The method developed in chapter 7 alleviated these issues. The method used several different approaches compared to previously developed methods to assess field application variation. The main difference was the use of the static spread pattern rather than the transverse spread pattern, this gave a more accurate representation of application especially when the spreading vehicle was starting and stopping. Other differences included the use of points rather than polygons in the GIS analysis; allowing different spread patterns to be calculated from machine parameters (flow, disc speed, forward speed) at each geographic vehicle location. The static spread pattern (781.5 m<sup>2</sup>) was made up of 3126 individual points each representing a 0.5 x 0.5 m quadrant. Overlapping points were summed together to produce application surface. Application statistics were extracted using the same method developed in chapters 5 and 6. This method proved to be the most accurate in determining field application variation and could be used to assess the ability of current centrifugal spreading vehicles to be used for variable rate application. In the future this model has the ability to be reworked to incorporate climatic factors that may influence spreading characteristics. The only negative aspect of this approach was the intensive computer processing required to run simulation models.

Overall, field variation was predominantly higher than that expressed in previous work. The methods developed within this study can be used to derive a much more accurate assessment of field application accuracy; they also have the potential to provide feed back in advanced management systems including variable rate nutrient application.

Chapter 8 provided an economic evaluation of current spreading performance and showed the potential economic gains of using guidance and control systems on fertiliser application vehicles. The dairy system examined showed significant economic losses (\$66.18 ha<sup>-1</sup>) when using current spreading methods. However, achieving optimised driving, attainable when using guidance and control systems correctly, the loss could be reduced to \$46.41 ha<sup>-1</sup>. This saving was found to be economically viable to a farmer if the added cost of using a spreading vehicle equipped with this technology was no greater than \$2.47 ha<sup>-1</sup> above current spreading charges. Depending on capital cost, useful life and annual work rate the implementation of precision

agricultural equipment was also found to have an economic benefit to a spreading contractor business providing an increased rate of \$0.50 ha<sup>-1</sup> could be passed onto the farming business.

This study showed that there are both agronomic and economic opportunities for the implementation of precision agricultural equipment. However, there are a number of issues that need to be overcome in order for the technology to succeed at a commercial level. The most predominant issue is a lack of understanding of current performance levels and the associated effect on agronomic and economic performance of pastoral agricultural systems. A wider implementation of the methods developed in this study could provide industry participants with strong financial evidence as to the losses associated with fertiliser application in New Zealand agricultural systems, in particular dairy systems. This, in turn, would lead to the development of improved more adaptable application techniques.

### **9.3. MAJOR FINDINGS**

A summary of the major findings from the research is given below:

- Using a transverse test pattern to explain spreader performance should only be undertaken when an understanding of the variability that surrounds results from individual tests is known.
- Because of the inherent variability that exists within transverse distribution tests the calculation to establish a working width under a prescribed level of variation should be repeated several times. The width that is the most probable should be selected rather than the widest width achieved. A more accurate representation of a spreader's working width is obtained when multiple rows and multiple passes without intervening weighing is used.
- The extraction of a wider range of particle information both pre and post spreading can help explain the interaction between the spread material and the spreading mechanisms involved in the distribution.
- Described field application measurement techniques indicated that application variation during field operations were significantly higher than that defined from transverse spreader tests. Using current techniques it would be expected that field application variation would be approximately double that measured from a spreader test.

- Methods to measure field application need to consider the major parameters associated with variation, these include: vehicle position in the field; vehicle forward speed; material flow rate from the hopper and disc speed. The use of a footprint model of spread material was found to be the most accurate when using these defined parameters.
- Once an accurate measurement of field application can be achieved, the agronomic and economic impacts can be quantified through the use of modelling techniques presented in this thesis. From this study it was shown that over 15% of fertiliser related losses were due to misapplication. The use of a guidance and control system on the spreading vehicle could reduce this loss to less than 10% within a dairy farming system.
- For a dairy farming system it was found that the cost benefit of using a spreading vehicle equipped with basic precision agricultural equipment (guidance and flow control) was \$2.47 ha<sup>-1</sup> per application, therefore, in order for the implementation of such equipment to be profitable, per hectare charge out rates cannot be greater than this value unless other indirect values from precision application of fertiliser (e.g., environmental cost or N leaching reductions) can be identified.

The findings of this study give guidance for measuring the variability of fertiliser application at the farm, paddock and micro management scale. Methods to quantify field performance allowed the agronomic and economic effect of current spreading methods to be evaluated. In order for full precision agricultural methods to be applied to fertiliser application systems in New Zealand small steps need to be taken. Previous work in identifying nutrient requirements for different soil types, soil status and production levels have led to the development of sound nutrient budgeting techniques. The development of the Spreadmark (NZFQC, 2006) and Fertmark (NZFQC, 2002) quality assurance programs have provided controls in the manufacture and distribution of fertilisers. This work is the next step in the process of adopting full precision agricultural systems, future work required to complete the adoption process is described in the following section.

#### **9.4. FUTURE STUDY DIRECTION**

Future studies should investigate the integration of field nutrient application measurement techniques into current nutrient modelling procedures and quality assurance programs; at present all methods assume a perfectly uniform application of nutrients. Methods developed within this study provide the means to model nutrient flows at a much higher spatial resolution than is used currently.

Further investigation into holistic farm studies should be completed. Tools are now available to measure pasture production at a resolution similar to what can be achieved from nutrient application mapping. However, the influence of climatic and temporal conditions needs to be considered to complete the modelling process. An analysis of such data could potentially produce a large reduction in the error levels achieved by current pasture and crop modelling techniques.

A shift from testing the transverse distribution pattern of a spreader to foot print modelling of individual machines using measured characteristics (disc speed, flow rate etc.) should be considered. This type of testing is required to accurately model variable rate application systems to evaluate whether or not this technology is applicable to individual machines or a new approach is required. The revised application mapping technique described in Chapter 7 showed that small incremental changes in behaviour can have significant economic and agronomic implications and should be considered as a tool to evaluate operator performance. The ability of this model to be developed further to include the effects of topography, ground and climatic conditions to further increase prediction accuracy of fertiliser application should be investigated. The ability to produce fertiliser application maps as given in this study is a considerable advance from assuming perfectly uniform application of fertiliser from spreading vehicles. This information combined with other spatial datasets within a GIS (i.e., topography, soil characteristics and pasture production) can potentially be used to produce and execute sound management plans that can reduce waste and environmental harm.

This study investigated the economics of implementing guidance and control systems on single spreading units. Further implementation studies on a large commercial scale should be investigated. Costs for data processing and analysis should also be factored in along with human related factors such as driver fatigue and safety.

### **9.5. DISSEMINATION OF KNOWLEDGE**

Throughout the three year period of this PhD study knowledge and results were disseminated in a number of ways, these included: journal publications; conference presentations; conference proceedings; technical workshop presentations; farmer field days and numerous personal communications. Events that contributed to the dissemination of knowledge from this study are described below.

#### ***Journal publications***

Lawrence, H. G., I. J. Yule, J.R. Jones (2006). A statistical analysis of international test methods used for analysing spreader performance. *New Zealand Journal of Agricultural Research* 49: 451–463.

*Received 6 April 2006; accepted 20 September 2006*

Lawrence, H. G., I. J. Yule, M.G. Coetzee. (2007). Development of an image processing method to assess spreader performance. *Transactions of the American Society of Agricultural and Biological Engineers*,

50(2): 397–407. *Received 30 August 2006; accepted 5 January 2007*

Lawrence, H. G., I. J. Yule. (2007). Estimation of the infield variation of fertiliser application. *New Zealand Journal of Agricultural Research* 50: 25–32. *Received 13 April 2006; accepted 20 December 2006.*

Lawrence, H. G., I. J. Yule. (2007). A GIS methodology to calculate the in-field dispersion of fertiliser from a spinning disc spreader. *Transactions of the American Society of Agricultural and Biological Engineers*,

50(2): 379–387. *Received 25 July 2006; accepted 11 December 2006*

Lawrence, H. G., I. J. Yule. (2007). Modelling of fertiliser distribution using measured machine parameters. *Transactions of the American Society of Agricultural and Biological Engineers*, 50(4): 1–7. *Received*

*14 January 2007; accepted May 2007).*

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Lawrence, H. G., I. J. Yule (2006). An economic analysis of fertiliser application accuracy on New Zealand dairy farms. *New Zealand Journal of Agricultural Research* XX: xxx–xxx. *Received 1 February 2007; (Under Revision).*

Lawrence, H. G., J.R. Jones, I. J. Yule. (2007). A statistical comparison of international spreader test methods to test confidence in bout width calculations. *Powder Technology* XX: XXX–XXX. *Received June 2007, Accepted August 2007.*

***Conference presentations/proceedings***

Yule, I. J. H. G. Lawrence (2005). Describing variability in fertiliser application: A statistical approach. In: Currie, L. D, J. A Hanly ed. *Proceedings 18<sup>th</sup> Annual FLRC Workshop (Developments in fertiliser application technologies and nutrient management)*. Occasional Report No. 18. Fertiliser and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Lawrence, H. G., I. J. Yule, J. R. Jones, M. Hedley (2005). Testing the viability of existing ground spread fertiliser spreaders to perform variable rate fertilisation. *Precision agriculture '05*. Papers presented at the 5<sup>th</sup> European Conference on Precision Agriculture, Uppsala, Sweden.

Lawrence, H. G., I. J. Yule (2005). Accessing Spreader Performance for Variable Rate Fertiliser Application. *ASAE Annual International Meeting, Tampa, Florida*. Paper No. 051117.

Yule I. J., H. G. Lawrence, R. M. Murray (2005). Performance of fertiliser spreading equipment for precision agriculture applications. *1<sup>st</sup> International Symposium on Centrifugal Fertiliser Spreading*, Leuven, Belgium.

Lawrence, H. G., I. J. Yule (2006). Calculating overall system CV in a ground spread application scenario. In: Currie, L. D, J. A Hanly ed. Proceedings 19<sup>th</sup> Annual FLRC Workshop (Implementing sustainable nutrient management strategies in agriculture). Occasional Report No. 19. Fertiliser and Lime Research Centre, Massey University, Palmerston North, New Zealand. Pp. 409-414.

Yule, I. J., H. G. Lawrence R.I. Murray (2006). Variables in Paddock Management. Landwise Conference, Keeping our Soils Productive. May 16<sup>th</sup> – 17<sup>th</sup> 2006, Havelock North, New Zealand.

Yule, I. J., H. G. Lawrence (2006) Developments in methods of in-field spreader testing. New Zealand Groundspreader's Association annual meeting (NZGSA). July 2006, Auckland

Lawrence, H. G., I. J. Yule, R. M. Murray (2006). Calculating field CV's for centrifugal spreaders. 2<sup>nd</sup> International Symposium on Centrifugal Fertiliser Spreading, Cemagref, Montoldre, France. October 2006.

Lawrence, H. G., I. J. Yule (2007). Application modelling of ground based spreading vehicles. 20<sup>th</sup> Annual FLRC Workshop (Designing sustainable farms: Critical aspects of soil and water management). Fertiliser and Lime Research Centre, Massey University, Palmerston North, New Zealand. *Poster presentation.*

Yule, I. J., H. G. Lawrence (2007) A Method for Calculating the Economic Impact of Poor Fertiliser Spreading. 2007 Annual International Meeting of the ASABE. June 17-20 2007, Minneapolis, Minnesota. (*Accepted for publication*)

#### ***Technical workshop presentations***

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## APPENDIX A

### DERIVATION OF $S_{d,i}^2 \approx 2S_i^2$

Where the difference between adjacent measurements is

$$d_i = x_i - x_{i+1}. \quad (\text{a1})$$

The variance of the differences for  $n$  measurements is then

$$S_d^2 = \frac{\sum_{i=1}^{n-1} d_i^2}{n-2}. \quad (\text{a2})$$

It is commonly assumed that this difference variance is equal to twice the variance about the mean,

$$S^2 = \frac{\sum_{j=1}^r (x_j - \bar{x})^2}{n-1}. \quad (\text{a3})$$

Equation (a2) can be rearranged as follows:

$$\begin{aligned} S_d^2 &= \frac{\sum ((x_i - \bar{x}) + (\bar{x} - x_{i+1}))^2}{n-2} \\ &= \frac{\sum ((x_i - \bar{x})^2 + (\bar{x} - x_{i+1})^2 + 2(x_i - \bar{x})(\bar{x} - x_{i+1}))}{n-2}. \end{aligned}$$

For large  $n$   $\sum (x_i - \bar{x})^2 = \sum (\bar{x} - x_{i+1})^2$ , therefore the difference variance is equal to

$$S_d^2 = \frac{\sum 2(x_i - \bar{x})^2 + 2(x_i - \bar{x})(\bar{x} - x_{i+1})}{n-2}.$$

Expanding and simplifying gives

$$\begin{aligned} S_d^2 &= \frac{\sum (2(x_i - \bar{x})^2)}{n-2} + \frac{\sum 2(x_i - \bar{x})(\bar{x} - x_{i+1})}{n-2} \\ S_d^2 &= 2S_i^2 + \frac{\sum 2(x_i - \bar{x})(\bar{x} - x_{i+1})}{n-2}. \end{aligned}$$

The terms within the summation of the second term are equally likely to be positive or negative, which means the summation for large  $n$  is zero. This result is implicit from figure A.1.

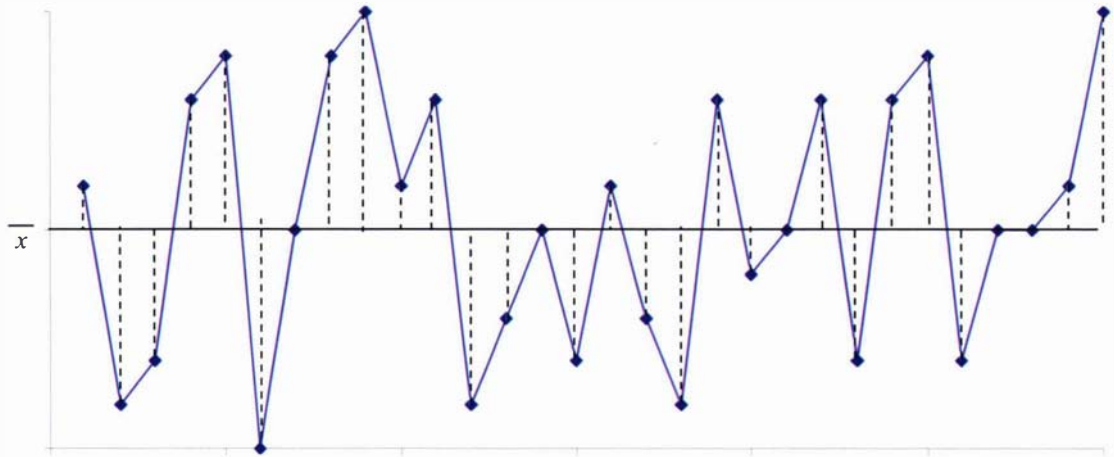


Figure A.1. Random measurements showing the differences of values from the mean. Differences between measurements are the sum of these terms.