THE EFFECT OF FERTILISER PARTICLE SIZE ON SPREAD DISTRIBUTION

Ian Yule

NZ Centre for Precision Agriculture, Massey University, Palmerston North, New Zealand

Abstract

Delivering a consistent and accurate fertiliser spread pattern is a key requirement for the spreading industry to meet current farming requirements and expectations. A large number of factors have been identified as having an effect on the distribution of fertiliser particles from a centrifugal spreader; these can be broken down into three main categories, relating to the environment where the spreading is taking place, the machine being used to spread the fertiliser and the fertiliser's characteristics. This paper will concentrate on the physical characteristics of the fertiliser material, with particular reference to particle size distribution within the material and the effect on spread pattern.

Due to the significant financial implications of inaccurate spreading, a great deal of scientific effort has been devoted to analyse and mathematically model the fate of fertiliser from a spinning disc. A number of approaches have been taken and these are reviewed to explain overall behaviour. Very little field work has been completed that would help explain and quantify what is happening in terms of the effect of particle size on spread distribution.

A field study funded by the Fertiliser Manufacturers Research Association (FMRA) to investigate issues around spreading blended fertilisers was used to attempt to analyse the fate of particles of different sizes from a Superphosphate Potassium Chloride blend. Two loads of the blend were spread and the Superphosphate used was found to have differing physical characteristics and this was used to form an estimate of the effect of changes in particle size. A total of 1700 tray samples were analysed in detail and the particle size distribution of their contents measured, allowing the spread distribution of each particle size to be recorded. To allow for the fact that different amounts were being captured within individual transect tests the percentage of the particle sizes captured was calculated, transects from both loads were compared and found to be reasonably consistent on that basis. This information was then used to simulate different materials to estimate the effect of changes in particle size distribution on spread pattern of superphosphate.

Introduction

Approaches to modelling particle flow off centrifugal spreader discs.

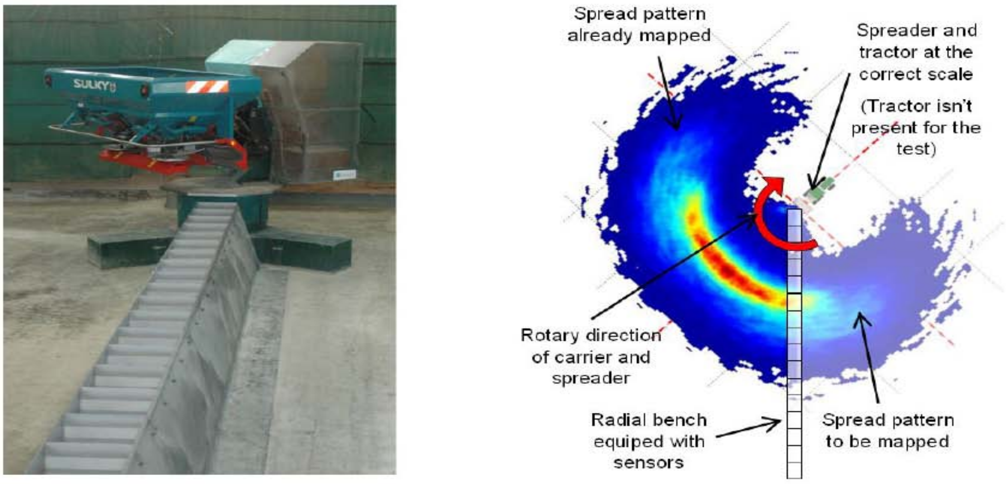
Centrifugal fertiliser spreaders dominate the market in most agriculturally developed countries; their main advantage is their low price, wide application width and high output. Their main disadvantage is the sensitivity for spread characteristics to change with environmental conditions and the material being spread. This is a topic which has been the focus of a great deal of investigation and research due to its economic importance. There are a number of different approaches taken to characterise the fate of fertiliser particles off a spinning disc spreader. The whole exercise is fraught with difficulty and uncertainty where a large number of factors can have a pronounced and immediate effect.

The first major hurdle is to accurately represent what is happening off the disc. Initial models such as Patterson and Reece (1962) and Inns and Reece (1962) assumed that the fertiliser flowed along the vane and was propelled off the end of the vane. Cunningham et al (1967), Griffis et al (1983) and Aphale etal (2003) also contributed to the effort of understanding machine design features and simulating distribution patterns. Olieslagers et al (1996) also took account of particles bouncing off the disc vane in comprehensive modelling work based on laboratory experimental observations. The same phenomenon was observed by the author on the spreader later described in this paper using a high speed video camera. Many spreaders in New Zealand are required to spread a wide range of materials from compound fertilisers, superphosphate, agricultural lime and even chicken manure, this leads to a more aggressive vane and disc design which probably results in a large proportion of particles coming off the disc in this fashion rather than flowing down the vanes.

Particle ballistics are reasonably well understood, part of the problem lies in the fact that the particles themselves are not uniform and many of the characteristics mentioned in Table 1 vary particle by particle. The population of particles on a spreader disc at any moment in time is variable in size shape, density, exit speed and angle. The result is that the precise laboratory measurements and derived relations then have to be surrounded by a large number of assumptions which can lead to modelled results being somewhat subjective. It is noticeable that most work is completed with urea or some other product with well defined particle properties; a product like superphosphate does not lend itself to this type of work and has largely been ignored by researchers. The results are only really applicable to the physical setup of the experiment, change one factor and the resulting distribution pattern will change. Feed pour-on point from the hopper to the disc is an obvious example, each manufacturer has a different shape and orifice position in relation to the disc position, therefore spreader distribution is different. Many of the laboratory experiments measured the final destination of the particle or trajectory by catching the particles after they had left the disc and subsequently weighing the collected samples. This meant that experiments tended to be extremely time consuming and expensive.

Laboratory based experimental work to measure exit speeds and trajectories can achieve good levels of accuracy under laboratory conditions, one example of this, the work of Grift et al (2002), who designed an optical sensor using an OptoSchmitt sensor array capable of measuring the size and velocity of particles passing through the double array, Grift (2006) also used laboratory methods to measure the friction coefficient of fertiliser in real time. These approaches helped to speed up the experimental process and gave accurate estimates of a particles final landing position. Other approaches using cameras to capture images Villette et al (2010) or blurred images have also been used. The shortcomings of this method are that it is two dimensional and some variability was inevitable due to the fact that the height of particles off the disc could not be detected. Camera systems were often limited in practical application due to the required camera angle. Blurred imaging techniques developed by Villette et al (2010) have also been used to estimate mass flow distribution.

A more modern facility developed by CEMAGREF in France has allowed some of those issues to be overcome. The facility described by Piron et al (2010a) allows a full footprint of a spread pattern to be determined. The spreader is rotated on a turntable and the automatic catch trays are continuously weighed, thus the contents of the catch trays which are a fixed distance but variable angle to the spreader can be used to determine spread footprint, building a two dimensional matrix of spread. Figure 1, reproduced from Piron et al (2010a) illustrates the ability to build this pattern. The CEMIB software system used in the system calculates the footprint and this system has been used to improve the design of spreaders. This level of analysis has not been possible before and the spreaders can be quickly re-tested and changes in design rapidly assessed. A number of European companies appear to be using this facility to good effect to improve the design of their machines as reported by Piron et al (2010b). This design of testing hall appears to have superseded previous designs where vehicles were driven over lines of catch trays arranged in a perpendicular pattern to the vehicle direction. However, even in this system the sampling is only for fertiliser mass rather than particle size distribution within individual samples.



Figures 1a, The CEMAGREF CEMIB device. Figure1b, A diagram illustrating the general principle of operation. Reproduced from Piron et al (2010a).

The other end of the spectrum is to carry out field measurements; an example is used later in this paper. There are also a number of limitations to this approach; again the results are generally only applicable to the particular experiment, the machine, the material and the environment. Each machine will have different factors affecting results and a large number of extremely time consuming experiments will have to be completed. Conducting experiments where individual tray samples have to be weighed is considered time consuming, but separating out individual particles sizes is seen as unrealistic. Hence the reasons for interest in optical methods of measurement to speed up this process and collect superior data. The main difficulties encountered here is the ability to deal with small particles. It is extremely hard to recognise small individual particles with sufficient accuracy, as described by Yule and Pemberton (2009a). One of the issues with field testing machines has been that as wheel arrangements for larger spreaders have become wider, with double tyre or even triple tyre arrangements in use, this means that up to six trays have to be removed from around the centre of the transect to allow the spreader to pass the line of trays, again arranged perpendicular to the direction of vehicle travel. Due to the heavier application around the transect centre; the fact that a higher proportion of the fine material is around the centre the fate of these particles is then difficult to analyse.

Particle characteristics

A number of authors have sought to identify the physical characteristics of fertiliser which change spreading characteristics. Hofstee and Huisman (1990) and Millar (1996) conducted reviews where these characteristics were identified. These are illustrated in Table 1. Hofstee identified characteristics in four categories, looking at storage, transport, as well as particle motion in the distributor and through the air. Millar identified the same factors and compared their effect on distribution and metering performance. Thirteen common factors were identified; particle size and particle size distribution affected all categories of concern. Pockele and Miserque (2005) provided useful information in regard to particle size distribution within a product and segregation.

Physical Property	Storage	Transport	Particle motion in:		Distribution Performance	Metering flow
			Distributor	Air		
Particle Size – Mean	X	X	X	X	X	X
Particle Size – distribution	X	X	X	X	X	X
Coefficient of Friction	-	-	X	-	X	X
Coefficient of restitution	-	-	X	-	X	-
Particle strength	X	X	-	-	X	-
Particle density	X		X	X	X	X
Particle shape	X		X	-	X	X
Aerodynamic resistance	-		-	X	X	-
Critical relative humidity	X	X	X	-	-	X
Bulk density	X	X	-	-	-	X
Angle of repose	X	X	-	-	X	X
Segregation properties	X	X	-	-	- (1)	- (2)
Caking tendency	X	-	-	-	-	-

Table 1. Physical properties of fertiliser which influence storage, handling and spreading. Columns 2 to 4 from Hofstee and Huisman (1990), columns 5 and 6 summarised from Millar (1996).

Olieslager et al (1996), Table 2, related machine factors and spreader setting to spread pattern, they characterised the disc, vane and orifice effect on spread pattern as well identifying environmental factors which also have an effect. A number of particle characteristics were also identified.

Model Parameters			
Spreader Settings		**Particle characteristics**	**Environment**
Disc	Radius (R_d) Cone angle (α) Distance between two disc centres (A_d) Angular velocity (ω)(*) Height above the ground (h)(*)	Particle density (ρ_p) Particle size distribution (D) Friction coefficient particle - disc (fd) Friction coefficient particle - vane (fv) Drag Coefficient (C_d) Coefficient of restitution (ε)	Air Density (ρ_a) Disturbances, Wind influences Speed variances Vibrations, shaking
Vane	Pitch (r_p) Shape (straight) (logarithmic spiral) (circular) (parabolic)		
Orifice	Shape Segment Inner radius (r_b) Outer radius (r_e) Segment angle ($\varnothing_d$) Other shapes Position ($\varnothing_o$)		

(*) Adaptable during operation.

Table 2. Model parameters used by Olieslager et al (1996) to describe factors affecting spreader performance.

None of the methods or studies described has attempted to separate particles of different particle size diameters or range of particle sizes in terms of spread pattern. This has always been perceived as too time consuming and most optical methods even under controlled laboratory conditions fail to record small particles and materials such as urea are often used in these experimental works. Little evidence of laboratory experimental work using products such as superphosphate exists.

Method

In order to determine the fate of particles of different size from a spreader an experiment to look at spreading a Potassium Chloride - Superphosphate blend was used to determine the effect of particle size on the superphosphate fraction of the loads. The blending experiment was described in Yule and Pemberton (2009b) the two loads used had superphosphate of different particle characteristics (sieve size analysis) as illustrated in superphosphates 1 and 2 in Table 3. Each load was spread and 28 transects were used over the whole load, initially this was done to examine any differences in product mix throughout the load. Each tray within the 28 transects were individually weighed and then a sieve analysis was conducted on each sample, with each fraction being weighed, the fractions of KCl and superphosphate had to be physically separated, attempts to do this through machine vision failed due to cross contamination of the samples and failure to accurately detect smaller particles, less than 0.5mm in diameter. The sieve sizes used are detailed in Table 3. Superphosphate 1 had a higher proportion of fine material and the effect on spread pattern was measured. Descriptions of Superphosphates 3 and 4 were obtained from “FertResearch” from dispatch analysis from plants. These were random samples and Superphosphate material 3 represents what could be considered typically the worst material you could expect in any year, while material 4 was the worst in the eight year period (2002 – 2009) where figures were available. Some care should be taken with these figures, as it should be borne in mind that these analysis were conducted at dispatch from the fertiliser plant, characteristics can change through transport and storage and it is important to re-emphasise that spreader operators should use sieve boxes to understand the material they are dealing with. The aim of this study was to use materials 1 and 2 to examine behaviour to see if materials 3 and 4 could be included and their effect on spread pattern estimated.

Sieve Size	Superphosphate 1 (1)	Superphosphate 2 (2)	Superphosphate 3	Superphosphate 4
Pan	11.4	5	25	16
0.4mm	25.8	11.5	30	30
1 mm	42.6	34.5	30	35
2 mm	12.3	22.7	12	10
2.8 mm	3.8	10.8	3	5
3.35 mm	2	7.5	0	2
4 mm	2	7.8	0	2

Table 3. Sieve size analysis of Superphosphate used in analysis and prediction.

Results

The actual quantity of fertiliser in each transect varied and this had to be taken into account by using the distribution of the percentage of each sieve size sample across each transect. The results of the distribution are illustrated in Figures 2a to 2g, the lines represented are from the Superphosphate (1) in (blue) ▲ and Superphosphate (2) in red 🟥. Each line is from the 28 transects sampled. Although the materials were different in sieve size analysis the comparison on the basis of percentage of each sample gave close agreement between the loads, this gave confidence to simulate further materials. A series of sixth order polynomial regression equations were developed and these provided a very high degree of explanation of the spread pattern measured in the blending trial. The regression coefficients for the range of sieve sizes tested were as follows, Pan, 0.94; 0.4mm, 0.97; 1mm, 0.98; 2mm, 0.99; 2.8mm, 0.95; 3.35mm 0.73; 4mm, 0.32. The lower values for the larger particle sizes can be explained by the flatter spread pattern across the width of the spreader. These equations were then used to simulate the effect on spread pattern of using the further materials specified in Table 3.

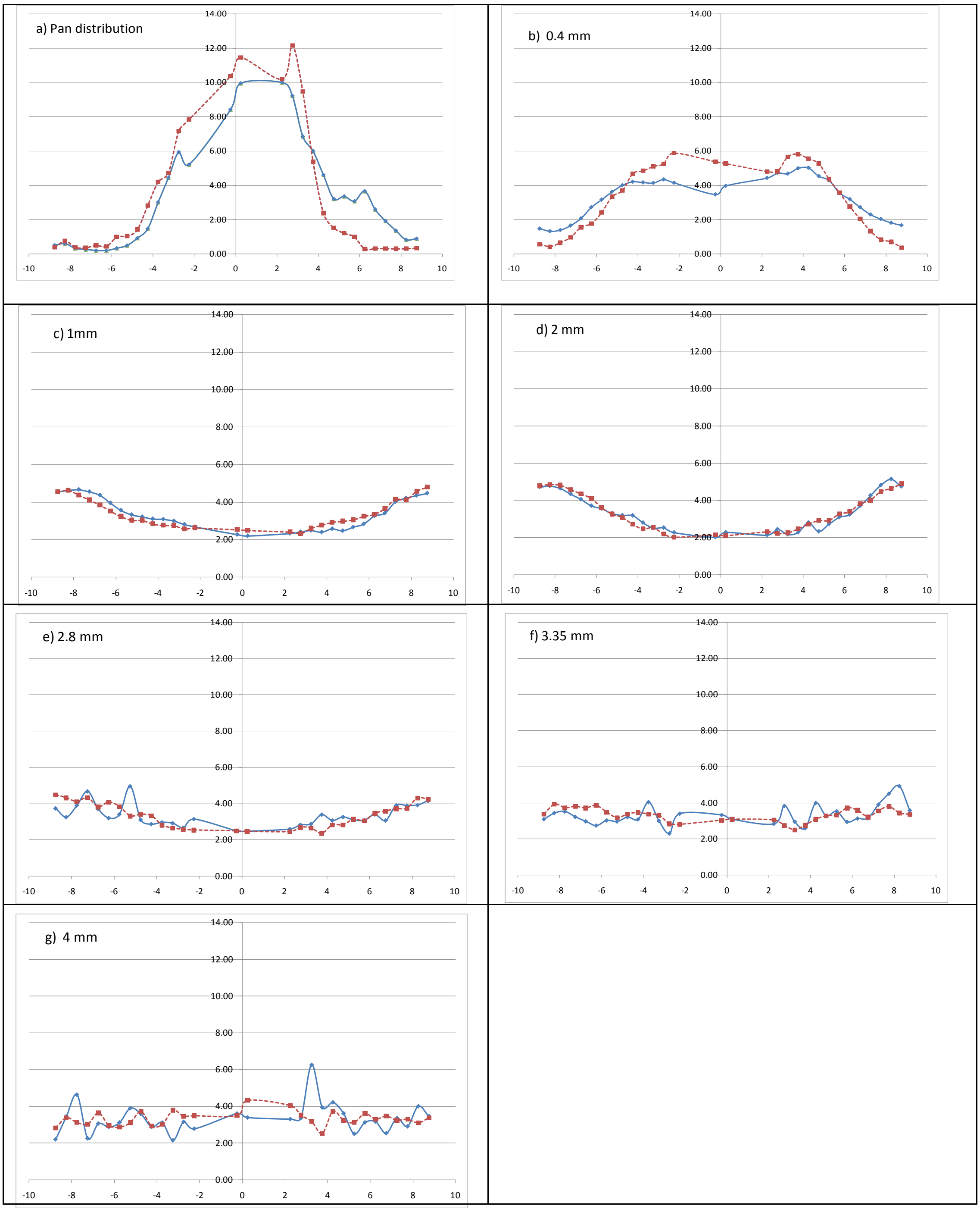


Figure 2. (a to g) Percentage of superphosphate particle size distribution spread over the width of spreader using two loads of a superphosphate and KCl mix. Where: ▲Material 1, 🟥 Material 2.

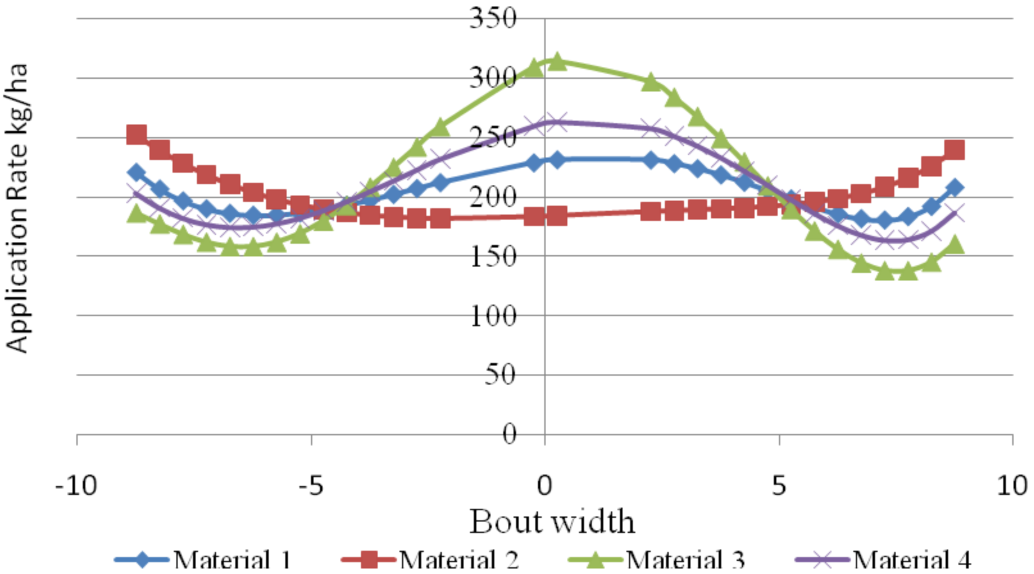


Figure 3 Estimated changes in spread pattern for the four materials described in Table 3.

The simulation suggests that as the proportion of small and pan material increases then the spread pattern will have a more peaked pattern around the centreline of the spreader. This has been of particular concern to groundspreaders. The effect of using material 4 (the worst material in 8 years) would be to increase spread CV by 16%, the effect of using material 3 (worst material you could expect in any one year) has been simulated as increasing CV by 5%. It must be remembered that these are the results from the worst materials and as such these should only be encountered by spreaders extremely rarely. Where relatively minor changes in particle size distribution are encountered then the effect should be minimal.

Conclusions

Provided the proportion of pan material does not exceed 15% then it is unlikely to cause a major problem in terms of disturbing the CV of the spreader by more than 5%. However go beyond that level and the spread pattern will have a very heavy application around the centreline of the spreader. Excessive fines will also cause dust problems and could lead to drift and off-site application in the presence of wind. The machine is also likely to require more regular cleaning.

This work is limited to representing the performance of one spreader with one fertiliser, with its settings used on the day of the trial, under the environmental conditions on the day of the trial. It is recognised by the author that further work is required but this is unlikely to happen as analysing each tray from field testing is too time consuming and the laboratory measurement techniques reviewed are not capable of measuring the fate of the small particles of interest here. The system described by Piron (2010a) is extremely comprehensive but even that system is not capable of discriminating between different particle sizes across the spread pattern.

The materials (3 and 4) used in the simulation were from factory dispatch and it is conceivable that the condition of a material could deteriorate in transport and storage, increasing the proportion of fines. Stability of material, correct storage and transport are clearly important in maintaining the physical integrity of the material. Testing the product using the Spreadmark sieve box is a way to help avoid problems by making the driver aware of the particle size range of the material they are dealing with. Trained and experienced drivers will know if machine settings can be altered to maintain an even spread pattern in the presence of an increase proportion of fines.

Acknowledgements

The author would like to thank Himitangi Transport for their assistance in conducting the field trial, and the FMRA for funding the blending trial used to provide raw data for the study.

References

Aphale, A., Bolander, N., Park, J., Shaw, L., Svec, J., & Wassgren, C. 2003. Granular Fertiliser Particle Dynamics on and off a spinner Spreader. *Biosystems Engineering, 85*(3), 319-329.

Cunningham, F. M., & Chao, E. Y. S. 1967. Design relationships for centrifugal fertiliser distributors. *Transactions of the American Society of Agricultural Engineers, 10*(1), 91-95.

Fulton, J. P., Shearer, S. A., Higgins, S. F., Hancock, D. W., & Stombaugh, T. S. 2005. Distribution Pattern Variability of Granular VRT Applicators. *Transactions of the ASAE, Vol. 48(6),* 2053-2064.

Griffis, C. L., Ritter, D. W., & Matthews, E. J. 1983. Simulation of rotary spreader distribution patterns. Transactions of the American Society of Agricultural Engineers,Vol26(1), 33-37.

Grift, T.E., Hofstee, J.W., 2002. Testing an outline spread pattern determination sensor on a broadcast fertiliser spreader. Transaction of the American Society of Agricultural and Biological Engineers, Vol.45(3):561 – 567.

Grift, T.E., Kweon, G., Hofstee, J. W., Villette, S. 2006. Dynamic friction coefficient measurement of granular fertiliser particles. Biosystems Engineering 95(4): 507 -515.

Hofstee, J.W., Huisman, W. 1990. Handling and spreading of fertilisers part 1: physical properties of fertiliser in relation to particle motion. Journal of Agricultural Engineering Research, 47: 213 - 234.

Inns, F.M., Reece, A.R., 1962. The theory of the centrifugal distributor II. Motion on the the disc, off-centre feed. Journal of Agricultural Engineering Research. 7(4):345 – 353.

Millar, P. C. H., 1996. The measurement and classification of the flow and spreading characteristics of individual fertilisers. Proceedings of the Fertiliser Society No. 390.

Olieslagers, R., Ramon, H., & De Baerdemaeker, J. 1996. Calculation of fertiliser distribution patterns from a spinning disc spreader by means of simulation model. *Journal of Agricultural Engineering Research, 63*, 137-152.

Patterson, D. E., & Reece, A. R. 1962. The theory of the centrifugal distributor. I: Motion on the disc, near-centre feed. Journal of Agricultural Engineering Research, *7*(3), 232-240.

Piron, E., Miclet, D., Villette, S., 2010a CEMIB: an innovative bench for spreader eco-design, Proceedings International Conference on Agricultural Engineering, AgEng2010, Clermont-Ferrand, France, 6 - 8 September.

Piron, E., Miclet, D., Leveille, L., Clochard, D., Villette, S. 2010b Mineral spreader eco-design: method and real application examples. Proceedings International Conference on Agricultural Engineering, AgEng2010, Clermont-Ferrand, France, 6 - 8 September.

Pockele, S., Miserique, O., 2005. Introduction to guidelines for the production and handling of blended fertilisers. Proceedings of the Fertiliser Society No. 558.

Tissot S, Miserque O, Quenon G 1999. Chemical Distribution Patterns for Blended Fertilisers in the Field. Journal of Agricultural Engineering Research 74: 339-346.

Villette, S., Gee, C., Piron, E., Martin, R., Miclet, D., Paindavoine, M., 2010. Centrifugal fertiliser spreading: velocity and mass flow distribution measurement by image processing. Proceedings International Conference on Agricultural Engineering, AgEng2010, Clermont-Ferrand, France, 6 - 8 September.

Yule , I., Pemberton, J., 2009a. Digital imaging for spreader testing. 22nd Annual FLRC Workshop In: *Nutrient Management in A rapidly changing world*.. (Eds L.D. Currie and C.L. Christensen). Occasional Report No. 22. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. Pp. 221 – 226.

Yule,I., Pemberton, J. 2009b. Spreading Blended Fertilisers. 22nd Annual FLRC Workshop In: Nutrient Management in A rapidly changing world. Eds L.D. Currie and C.L. Christensen). Occasional Report No. 22. Fertiliser and Lime Research Centre, Massey University, Palmerston North, New Zealand. Pp. 243 – 249.