Impact recording system to characterise centrifugal spreading

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Abstract
This paper presents a new method to measure simultaneously the horizontal and vertical distribution of the mass flow in the vicinity of the spinning disc of fertiliser centrifugal spreaders. The method consists in recording granule impacts on a cylindrical vertical screen placed around the disc. Algorithms have been developed to process the impact recording band taking into account its location with respect to the spreading device. The distribution of the mass flow has been studied for three fertilisers. Our findings show that the horizontal and vertical distributions of the mass flow are similar for ammonium nitrate and NPK, while they are different for KCl. For each fertiliser, the horizontal distributions deduced from impact records are in accordance with results deduced from a traditional compartmented ring. This new method is useful to study the vertical distribution of fertiliser granules and paves the way to design simple test and diagnostic tools.

Keywords
Centrifugal spreading, fertiliser, two-dimensional mass flow distribution, impact recording

1. Introduction

Several methods have been proposed to measure the fertiliser distribution obtained with centrifugal spreaders. The most traditional method consists in measuring the transverse distribution by using collection trays lined perpendicularly to the travel axis of the tractor. This requires large test halls and high amounts of fertiliser for each test. In field, transverse distributions can also be measured to evaluate the distribution uniformity and adjust spreader settings, but these measurements are tedious and rarely carried out by operators in practice.
Concerning the understanding of the centrifugal spreading process, the transverse distribution curve results from the combination of all spreading parameters and it does not facilitate the study of the influence of each parameter such as: outlet velocity, outlet angle, horizontal and vertical mass flow distributions, fertiliser granule ballistic properties...
Considering the mass flow distribution around the disc as one of the results of the fertiliser acceleration, several authors suggested the use of a compartmented ring placed around the disc to study centrifugal spreading (Colin, 1997; Olieslagers, 1997; Reumers *et al.*, 2003a)), assess mechanical models (Van Liedekerke *et al.*, 2009), or characterise fertilisers (Miller, 1996; Dutzi, 2002; Miller and Parkin, 2005). The measurement of the mass flow distribution around the disc also provides a useful input parameter for ballistic flight models that can be used to predict the distribution pattern deposition on the ground. Thus, some authors (Miller, 1996; Reumers *et al.*, 2003b) suggested using this piece of information to develop an alternate method to traditional measurements of deposition pattern on the ground.
Although numerous authors have carried out the measurement of the horizontal distribution of the mass flow, few authors addressed the problem of measuring the vertical distribution. Mennel and Reece (1963) measured the amount of particle leaving a spinning disc and passing through an opening windows. Using a compartmented ring Olieslagers (1997) measured the percentage of the particle flow passing through the square entrances of compartments. Reumers *et al.* (2003a) equipped a compartmented ring with a vertically adjustable screen and deduced the horizontal and vertical distribution of the mass flow from a set of successive tests. Some negative values obtained by the authors in the distribution

measurements reflected the difficulties to carry out an accurate method using successive vertical screen positions in front of collection compartments.
The aim of this work is to propose a new approach to simultaneously measure the horizontal and vertical distribution of the mass flow in the vicinity of the disc by recording granule impacts on a cylindrical screen placed around the disc.

2. Materials and methods

2.1. Recording fertiliser impacts

In this study, the measurement method of the mass flow has been developed using an experimental spreading device built to study centrifugal spreading process and assess characterisation methods. The mechanical part of the system is made up of elements similar to those found in a traditional centrifugal spreader. For this study, a flat disc was equipped with two radial vanes. The vanes were 325 mm length and had a U-profile whose inner height was 28 mm. The spinning disc was driven by an electric motor whose rotational speed is set by a programmable power supply.

The experimental arrangement used to record fertiliser impacts around the spinning disc (*Fig. 1*) consists of a vertical and cylindrical sheet of iron placed on an adjustable stand. This cylindrical screen was centred on the spinning disc axle at 600 mm from the disc centre. The screen was covered with a paper band, a carbon film and a protective coat so that fertiliser granule shocks against the screen produce impact marks on the recording paper band. The horizontal and vertical location of the paper band was measured with respect to the disc so that the height of the impacts was known relative to the disc plane and the angular location around the disc was known relative to the mechanical frame of the spreading device. In particular, a horizontal line was drawn on the paper band before each use as a reference line. The vertical height of this line was measured with respect to the disc plane and the intersection of the reference axis of the mechanical frame was reported on this line to create the abscissa reference of the band. This line will be used in further data processing.
The exposition time of the recording paper to granule shocks was controlled by the total fertiliser amount placed in the hopper before shutter opening. When the shutter was opened, the size of the orifice at the bottom of the hopper was the same for all tests.

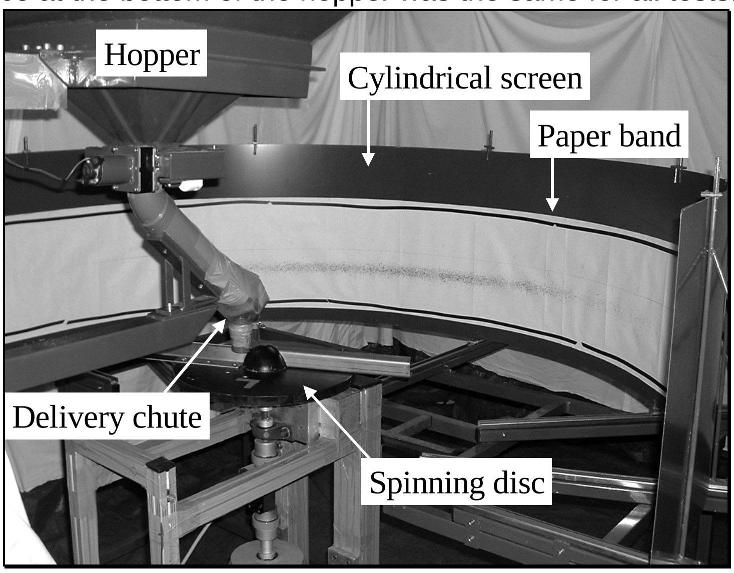

Fig. 1. Photograph of the cylindrical impact screen placed around the spinning disc

2.2. Processing impact records

First, vertical segments were drawn along the reference line crossing the line each 250 mm. The locations of these segments are known with respect to the reference axis of the mechanical frame of the spreading device. Second, the impacted paper band was digitalised section-by-section using a traditional desk scanner so that each section image showed two vertical segments along the reference line. Third, an automatic image processing was used to build a digital image of the whole band. The main steps of the algorithm are as follows:
(1) Using the Hough Transform (Hough, 1962; Duda and Hart, 1972) the reference line is automatically identified in each individual image and its inclination is measured relative to the pixel lines of the image. The image is then rotated so that the reference line becomes (after rotation) parallel to the pixel lines of the digital image. Note that this image-processing step perfectly locates the reference line in the image.
(2) The vertical segments crossing the reference line are automatically detected along the reference line. Their location is used to truncate the right and left sides of each section and to compute the pixel-millimetre conversion factor. The location of the segments along the reference line also ensures the horizontal angular positioning of the recorded data around the spinning disc.
(3) The digital image of the whole recording band is automatically built by assembling each section so that the vertical location of the reference line in the global digital image of the whole band is the same for all sections.
In order to make possible comparisons between measurement systems, the angular mass flow distribution has to be computed at the outer extremity of the vane. Assuming that granules follow straight trajectories during their short ballistic flight, the angular distribution at the extremity of the vane is deduced from the measured angular distribution, the inner radius of the measurement device and the horizontal outlet angle of granules. The horizontal outlet angle θ_{out} is the horizontal angle between the fertiliser granule trajectory and the tangent to the disc. This angle is measured using a digital camera placed vertically above the granule output flow. A specific image processing was used to deduce the outlet angle from motion-blurred images on which granule trajectories are identified. The imaging technique is detailed in Villette *et al*. (2008).

2.3. Measurements with a traditional compartmented ring

In order to assess the impact recording method concerning the horizontal angular distribution, some mass flow distribution measurements have been carried out using a cylindrical compartmented ring (*Fig. 2*). The ring consisted of 22 compartments of 10° each and its inner radius was 400 mm. The horizontal angular mass flow distribution was deduced from weighing the fertiliser amount collected by each compartment.

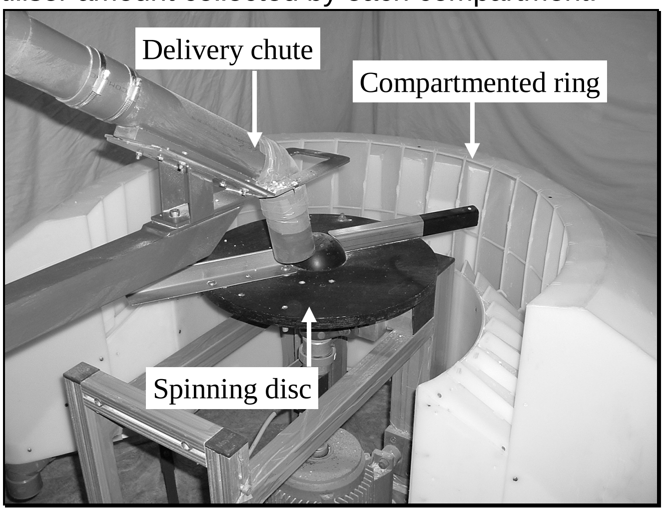

Fig. 2. Photograph of the compartment ring placed around the disc.

3. Results

Three different types of mineral fertilisers have been used in this study: ammonium nitrate, a compound fertiliser NPK 17-17-17 and potassium chloride KCl. These three common fertilisers are chosen to be compared because of their differences in granule shape, rounded in the case of ammonium nitrate and NPK but angular in the case of KCl.

3.1 Two-dimensional representation of the mass flow distribution

Setting the radius of the cylindrical screen at 600 mm, three impact bands have been recorded for each fertiliser: ammonium nitrate, NPK and KCl. For each fertiliser, *Fig. 3* shows an example of digitalized impact band represented in the same reference frame and millimetre-graduated scales. The vertical scale is exaggerated with respect to the horizontal scale to improve readability. Note that the abscissa axis is graduated from the left to the right, while the rotation direction of the vane is from the right to the left with the experimental spreading device. Thus, the beginning of the ejection is at the right side of the paper band and the end is at the left side.

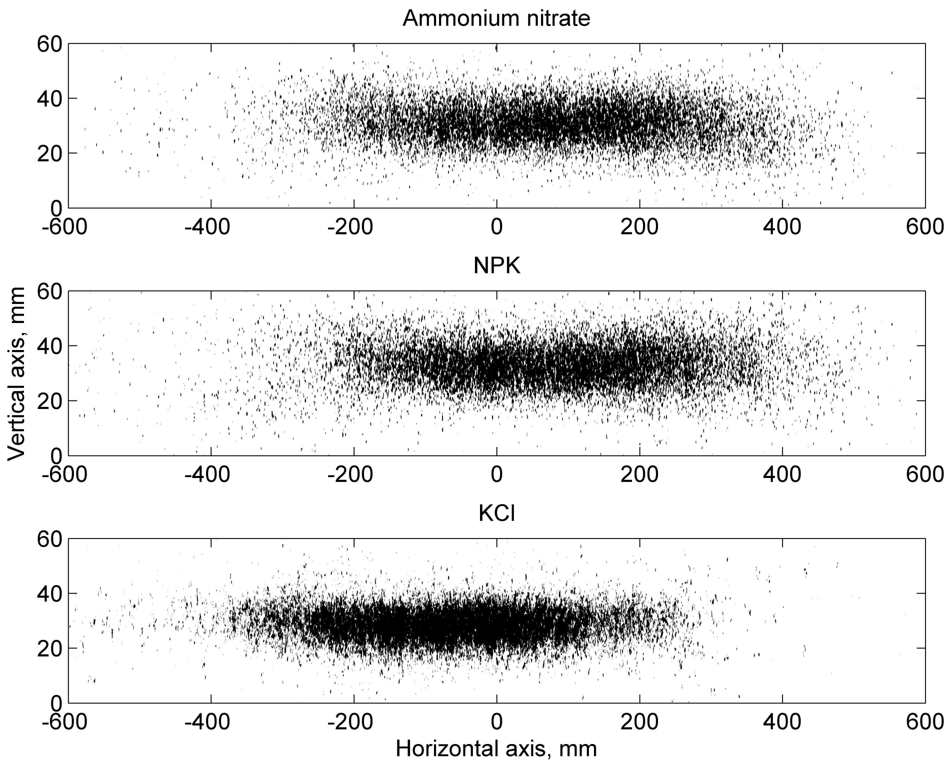

Fig. 3. Examples of binary digital images of the impact bands obtained after assembling each band section in the same reference frame for the three fertilisers. Vertical scale is exaggerated to improve readability.

While the impact bands seem similar for ammonium nitrate and NPK, a simple visual observation reveals that the impact distribution of KCl is horizontally shifted towards negative values. Regarding the experimental set-up, this means that the horizontal KCl distribution is shifted in the direction of the disc rotation.

Granule impacts are more dispersed at the beginning and the end of the spreading sector. This corresponds to granules whose freedom of vertical motion is higher on the vane. Moreover it seems that vertical dispersion of the impacts is more important in the case of ammonium nitrate or NPK than in the case of KCl. The shape of the granules could also

explain this. The rolling motion of rounded granules probably provides more diversity in the granule trajectories on the vane.
Note that most of the “pop-corn granules” are not recorded on impact band because of their lower velocity and thus their lower kinetic energy. These granules bounce off the vane or the disc and are not accelerated in the vane before ejection.
Assuming that the surface of impact marks in one area of the paper band is proportional to the fertiliser granule mass intercepted by this area on the screen, the percentage of the fertiliser mass intercepted in an area can be computed relative to the total fertiliser amount intercepted by the screen. In practice, the surface of impact marks lying on a specified area is simply obtained as the number of marked pixels in this area.

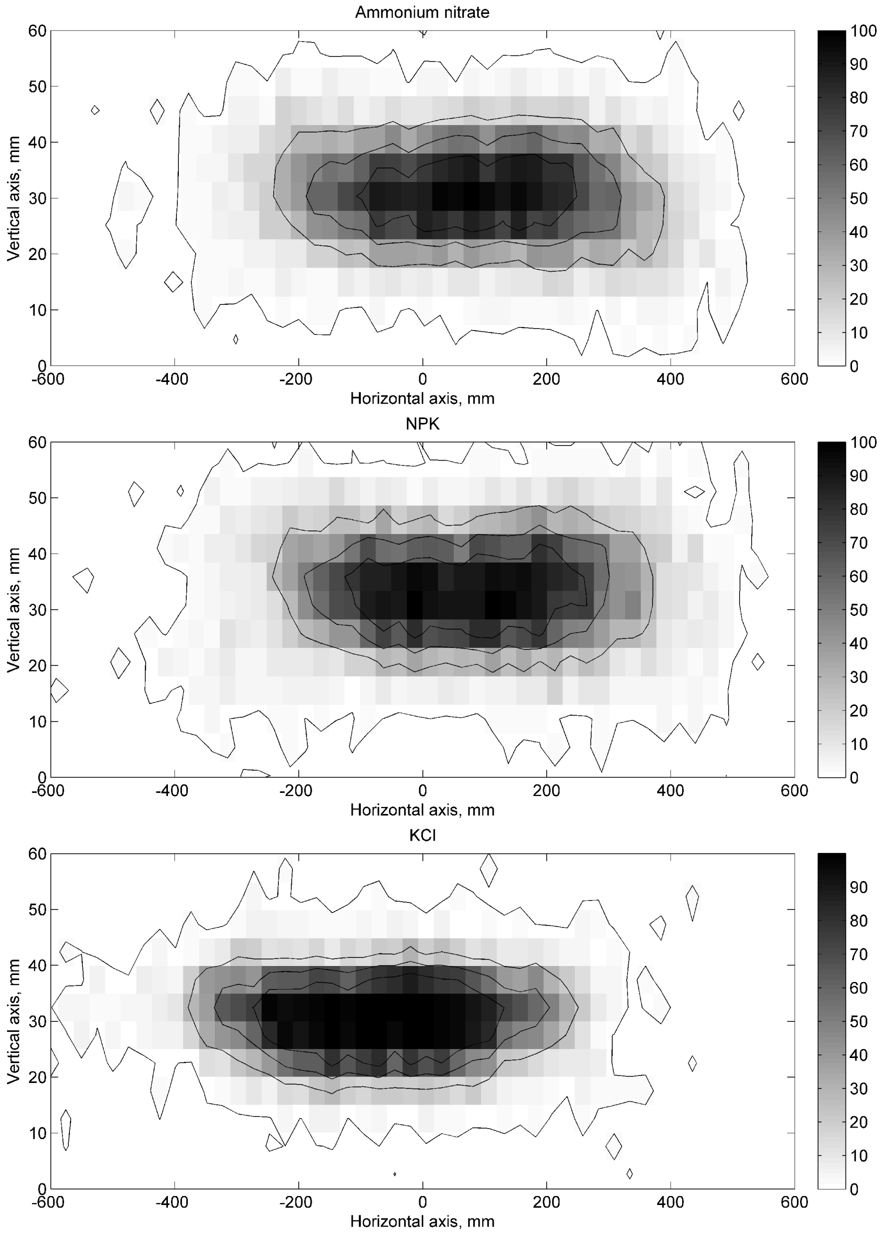

Fig. 4. Two-dimensional distribution of the mass flow. The grey scale corresponds to the fraction intercepted by the block (in percent) relative to the maximum intercepted amount by a sampled block (5 $\times$ 25 mm).

For instance, sampling the screen into blocks of 5 mm height and 25 mm wide, *Fig. 4* presents the two-dimensional distribution of the mass flow for each fertiliser. The grey level of each sampled block corresponds to the percentage of the impact density relative to its maximum value. For each block, this can be transformed into the intercepted amount fraction relative to the total intercepted amount on the whole screen. The most impacted block (5 $\times$ 25 mm) corresponds to 1.27%, 1.17% and 1.33 % of the total intercepted amount for ammonium nitrate, NPK and KCl respectively.

3.2. Measurements of the horizontal distribution

In order to characterize more accurately the horizontal distribution of the three fertilisers, the binary digital image of the impact bands have been processed by summing vertically the number of marked pixels along an horizontal axis with a sampling interval of one millimetre. Then taking into account the radius of the impact screen and the value of the outlet angle of fertiliser granules, the horizontal mass flow distribution has been computed with respect to the angular location of the vane. The mean value of the outlet angles deduced from blurred-motion images were: 40.1° for ammonium nitrate, 39. 5° for NPK and 34.8° for KCl.
For the three studied fertilisers, distributions deduced from impact recording bands have been compared to distributions measured with the compartmented collection ring. Figure 5 shows the distribution histograms obtained by both methods for the three fertilisers.
The impact distributions presented in *Fig.* 5 result from the three impact bands for each fertiliser type. To make possible the comparison, impact distribution data have been classified into the 22 angular sectors delimited by the ring compartments and transformed into angular vane location sectors. Table 1 presents the characteristic parameters of the distribution computed from each recording band (three bands for each fertiliser) and the mean values deduced for each fertiliser. It also presents the characteristic parameters of the distributions measured using the collection ring. The histograms and the distribution characteristics deduced from the impact recording method are in good accordance with those deduced from collection ring measurements. In particular, both methods demonstrate that the horizontal angular distribution is similar for ammonium nitrate and NPK while the distribution is shifted in the direction of the spinning disc for KCl. This confirms the previous qualitative visual appreciation regarding the impact 2D-distribution on the paper band. For instance, note that the difference observed in the angular mean value of the distribution at the extremity of the vane between ammonium nitrate and KCl corresponds to a difference of 160 mm on the cylindrical screen (radius: 600 mm).

Tab. 1. Characteristic values of the horizontal angular distributions deduced from the impact recording method and from the compartmented ring method: μ_θ, mean value; σ_θ, standard deviation

	Impact method				Compartmented ring	
	Successive measurements		Mean values			
Fertiliser	μ_θ	σ_θ	μ_θ	σ_θ	μ_θ	σ_θ
Am. nit.	56.2 °	17.0 °	56.5 °	17.6 °	55.4 °	18.6 °
	56.4 °	18.2 °				
	57.0 °	17.7 °				
NPK	56.0 °	18.7 °	56.6 °	17.8 °	55.5 °	18.9 °
	55.2 °	16.8 °				
	58.5 °	17.9 °				
KCl	70.4 °	17.2 °	68.4 °	17.2 °	70.8 °	17.2 °
	67.9 °	17.5 °				
	66.9 °	16.8 °				

Considering one and the same fertiliser (in particular for NPK and KCl in Table 1), variability appears in the mean values and standard deviations computed from the successive impact recording bands. This could result from fertiliser variability. Moreover, since each impact band measurement only corresponds to a small amount of material (530 g in the present tests), this could increase the sensibility of the method to fertiliser and spreading variability.

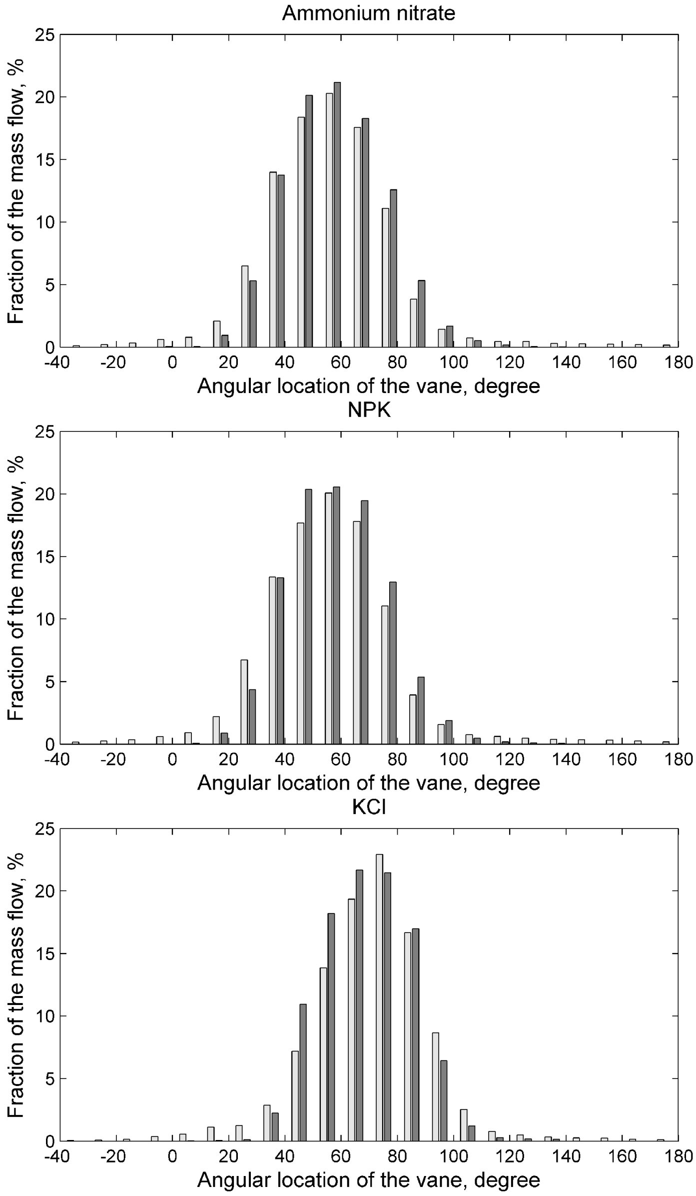

Fig. 5. Horizontal angular distributions of the mass flow deduced from the compartmented ring (light grey bars) and from impact records (deep grey bars) for three fertilisers.

3.3. Measurements of the vertical distribution

To characterise the vertical distribution of the mass flow, the binary digital images of the impact bands have been processed by summing horizontally the number of marked pixels along a vertical axis with a sampling interval of one millimetre. Table 2 provides height values measured in millimetres on the screen with respect to the disc plane altitude. Height mean values are at least the height of the vane, which is 28 mm. This needs some comments. Although a flat disc is used, the fertiliser particles do not follow horizontal trajectories in the vane. During their motion along the vane, fertiliser particles move to the upper fold of the vane so that their outlet heights are displaced toward the top of the vane and their

trajectories are tilted up. This phenomena probably depends on the mass flow rate but is observed in this study for low rate.
Regarding Table 2, the outlet height of ammonium nitrate or NPK appears higher than the one of KCl. This is due to the rolling motion of the rounded particles (*i.e.* ammonium nitrate and NPK) on the vane, which yields more vertical motion and variations in the orientation of the trajectories at the extremity of the vane. The standard deviation values (Tab. 2) also demonstrated that the vertical dispersion of ammonium nitrate and NPK is higher than the one of KCl.

Tab. 2. Characteristic values of the height distributions deduced from the impact recording method: μ_z, mean value; σ_z, standard deviation

	Successive measurements		Mean values	
Fertiliser	μ_z (mm)	σ_z (mm)	μ_z (mm)	σ_z (mm)
Am. nit.	30.3	8.1	29.9	8.3
	29.5	8.4		
	29.8	8.4		
NPK	32.4	9.1	31.4	9.1
	29.6	8.7		
	32.3	9.4		
KCl	28.0	6.8	27.8	6.9
	28.1	7.2		
	27.2	6.7		

In order to estimate the angular standard deviation of the flow vertical distribution, it is necessary to consider the height distribution of the particles on the screen and the length of the ballistic flight between the vane and the impact screen that are respectively 337 mm, 338 mm and 352 mm for ammonium nitrate, NPK and KCl.
Considering that the fertiliser flow leave the vane from only one point at the extremity of the vane, the angular standard deviations $\sigma_{\theta v}$ of the vertical flow distribution are respectively 1.35°, 1.39° and 1.10°. This means that more than 9 9% of the mass flow leaves the vane with an upward or downward vertical angle of 4.05°, 4.18° and 3.30° for ammonium nitrate, NPK and KCl respectively. Few studies addressed the measurement of the vertical distribution of the fertiliser mass flow around a spinning disc. For vanes with U-profile, Mennel and Reece (1963) reported that less than 25% of the particles left the disc with a vertical angle comprised between 3° upward and 3° d ownward. These findings are in complete disagreement with those obtained in the present study. The wide vertical dispersion observed by Mennel and Reece is probably due to the fact that individual particles were accelerated one by one on the spinning disc. In opposition, the present study examined the vertical distribution of an entire particle flow.
Using polypropylene particles and U-profile vanes of 40 mm height, Olieslagers (1997) reported that the amount of particles not captured between 4° upward and 4° downward were respectively 11.2% when the vanes were 280 mm length and 24.8% when they were 150 mm length. These results are much more in accordance with above-mentioned findings. Various parameters can explain discrepancies. In particular, differences have to be noted in the dimension of the vanes (length and height), in the disc rotational speed and in the particle nature. Reumers *et al.* (2003a) presented some 2D-distribution measurements around the spinning disc but do not provide any more accurate characteristics concerning the vertical distribution.
In the previous analysis, we assumed that fertiliser granules leave the vane at the same point on the vertical wall on the vane extremity. Mennel and Reece (1963) or Olieslagers (1997) implicitly used the same approach to transform height standard deviation into vertical angular standard deviation. In practice, this seems not realistic since granules can be at various heights in the U-profile when they leave the vane. Moreover the shape of the vertical

distribution of the mass flow at the extremity of the vane probably depends on the mass flow rate and the resulting vertical occupation of the vane. Thus, a better estimation of the vertical angular distribution can be obtained by measuring the distribution at two different distances from the spinning disc axle. For ammonium nitrate, the distribution has been measured with the same method but with a cylindrical screen radius set at 945 mm. At this radius, the mean value of the standard deviation of the impact height distribution is 13.81 mm. Combining the height standard deviations measured at these two different radii and taking into account the corresponding flight length between these radii, the vertical angular standard deviation is 0.92°. This value is logically lower than the one deduced from the first analysis. Considering this approach, 99% of the mass flow leaves the vane with an upward or downward vertical angle of 2.76° for ammonium nitrate.

4. Conclusion

The study demonstrated that recording impacts of fertiliser granules against an interception screen provides a new technique to instantaneously record the two-dimensional distribution of the mass flow around a centrifugal spreading device. A specific image processing has been developed to perform an accurate analysis of impact recording paper bands and compare findings to other distribution measurement devices. For three different fertilisers, the horizontal angular distributions deduced from the impact recording method are in agreement with those deduced from a traditional compartmented ring. In particular, impact records show that the distribution obtained for ammonium nitrate is close to the one obtained for NPK while the distribution obtained for KCl is clearly shift in the direction of the disc rotation. The study also demonstrates that impact recording is an efficient technique to measure the vertical distribution of the mass flow. Findings clearly show that the vertical standard deviation observed for KCl is lower than the one observed for ammonium nitrate or NPK.
For research work, the method can be used to study the centrifugal spreading process, characterise fertiliser mechanical behaviour or provide input data for ballistic flight model in order to predict the distribution pattern deposition on the ground. Adapting data acquisition and data processing, the study opens up the possibility of designing new simple tests and diagnostic tools to help users in setting their machine.

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