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Mineral spreader eco-design: method and real application examples

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Abstract

This paper shows how information enclosed in the 3D spread pattern measurements obtained with the CEMIB test bench can be used to support scientifically spreader improvements. The main aspects to consider during this first step of improvement are described and explained using real examples. The importance of an adapted choice of mean projection distance is shown, as well as the necessary choice of working width ranges for each disc...

Then specifications are expressed, as robustness evaluation of the transverse curves, since the beginning of the design. Relation with fertiliser characteristics is introduced, as well as the development of a spreading simulator.

Results, mainly articulate around the SULKY X Range spreader design, highlight the technical choices made by SULKY, and the performances reached, as well for main field or border applications.

Keywords

Centrifugal spreading, eco-design, spread pattern

1. Introduction

Centrifugal spreaders used for mineral applications are nowadays relatively complex, equipped with electronic devices and computers. They generally use 2 different spinning discs turning in opposite directions, positioned under a hopper, to spread fertiliser granules on the ground after a ballistic flight. Because of their simplicity in the concept, they are robust regarding different fertiliser types, easy to use, very efficient as well considering spreading performances or working velocity, and finally cheap regarding all these advantages.

Since the beginning of the use of this spreading process, many improvements have been proposed and developed: from the single spinning disc to the double discs, from simple mechanical and hand made settings to several electronic ones, with computer assistance directly useful from the cab.

Many reasons guided these successive innovations, either to improve the spreading performances, i.e. the different distribution homogeneity, or to make the different functions easier to use. Advances have very often been made step by step, and directly linked to the sprayer working width improvements: spreaders tramlines are often the same than sprayers ones.

In addition, regarding the distribution improvements, the only available development tool was the transverse bench, described in the EN13739-2 standard. Even if it represents a good way to evaluate real spreader performances, this method doesn't give real knowledges about the 3D spread pattern and its determinants. As the standard method integrates the spreader displacement parameter, it's almost impossible to go back to the 3D spread pattern. Nevertheless, this one is of major interest for the understanding of physical phenomena, for conception assistance, or to develop improvements.

Improving spreaders is also a complex but very important procedure for manufacturers. Even if they built up experience and if the Computer-aided Design (CAD) helps them to simulate a global mechanical work, no method is really available to predict the most important aspect, i.e. the spreading distribution quality.

Nevertheless, alternative ways have been explored to reduce the number of needed real tests, and to better take into account the physical phenomena and their eventual interactions, i.e. mechanical disc and vane characteristics, fertiliser physical properties ... A particularly interesting way is the use of Discrete Element Method (DEM) simulations, in particular presented by Van Liedekerke et al. (2006, 2009). A virtual spreader could be obtained, allowing the research of the best global organisation of all the spreading devices (vanes, drop zone shape and position, angular velocity ...). At the present time, this method can be used to help the design of a particular piece. Nevertheless, firstly, calculation time necessary to simulate an entire spreader is too important (linked to the number of particles) regarding the number of different simulation cases which should be necessary to obtain a "real" virtual spreader. Secondly, the model needs to be adapted to real tests to give similar answers. When a manufacturer wants to improve a part of his spreader, or a new function, he writes specifications to achieve, and then would like to reach them with the maximum of reactivity and control.

The aim of this paper is to show how the information enclosed in the 3D spread pattern can offer a more professional way to the manufacturers to improve centrifugal spreaders as well as fertiliser properties: from the first step of increased knowledge to the development step, and finally to the final checkings. Improvements have to be understood under the environmental aspects, i.e. in global goals of application defaults minimisation in the field.

Due to economical reasons, for example to minimize global development costs or building ones, spreaders are designed around an identical base, as well for the smallest or the biggest ones. The only different pieces are the discs, the arrangement around the hopper ... The paper is organised around the real development and improvement of the Sulky X Range spreader.

2. Methods and points to consider

This first part describes different sides of a scientific assisted development, allowed by the 3D spread pattern knowledge and the CEMIB (short for CEmagref MIneral Bench): what are the useful informations, which are the technical limitations to consider, and how to establish the link with a simulator.

2.1. The 3D spread pattern and the information enclosed

The mathematical analysis of a spread pattern obtained using a centrifugal disc has been performed in years 1990 to 2000, in particular by Colin (1997) or Olieslagers (1997). They both looked how the fertiliser granules densities were distributed on the ground after being spread by a centrifugal disc. One significant issue has been to express this fertiliser density using two Gaussian equations. The first for the radial distribution (driven by the mean projection distance – P_m – and its standard deviation - σ_p) and the second for the angular distribution (driven by θ_m and σ_θ).

As long as the spreader tests were carried out using the traditional standard EN13739-2 (EN 13739-2, 2003), it was almost impossible to extract this significant information, and so to fit the correct values in order to develop some spreading models.

The development of the Cemib, (Piron and Miclet, 2005) deeply changed the way to analyse centrifugal spreading performances. In addition to the practical interest of this device (it allows testing all centrifugal spreaders whatever their performances in a very short test hall measuring 10m * 40m), the Cemib, patented in 2005 by the Cemagref (Piron and Miclet, 2005), performs the measurement of the real 3D spread pattern, using a radial method for a radial phenomena. The spreader, coupled on a rotary carrier, spreads its fertiliser constantly while a radial positioned row of instrumented boxes allows a continuous measurement, angle by angle, of the distributed density (Piron and Miclet, 2005).

In a very short time (a few seconds or minutes), and without great fertiliser amounts (between 20kg and 80kg regarding the flow rate), the fertiliser density matrix is obtained (Fig. 1), allowing traditional calculations (transverse and overlapped curve, coefficient of variation curve).

Performed with only one fed disc, the measured "map" represents the result of a limited number of variability factors, and it becomes possible to extract models directly from the spread pattern. Fig. 2 illustrates two of these new calculations.

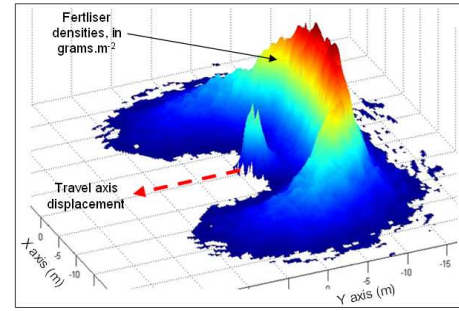


Fig. 1: Fertiliser density matrix obtained in a few minutes using the CEMIB device.

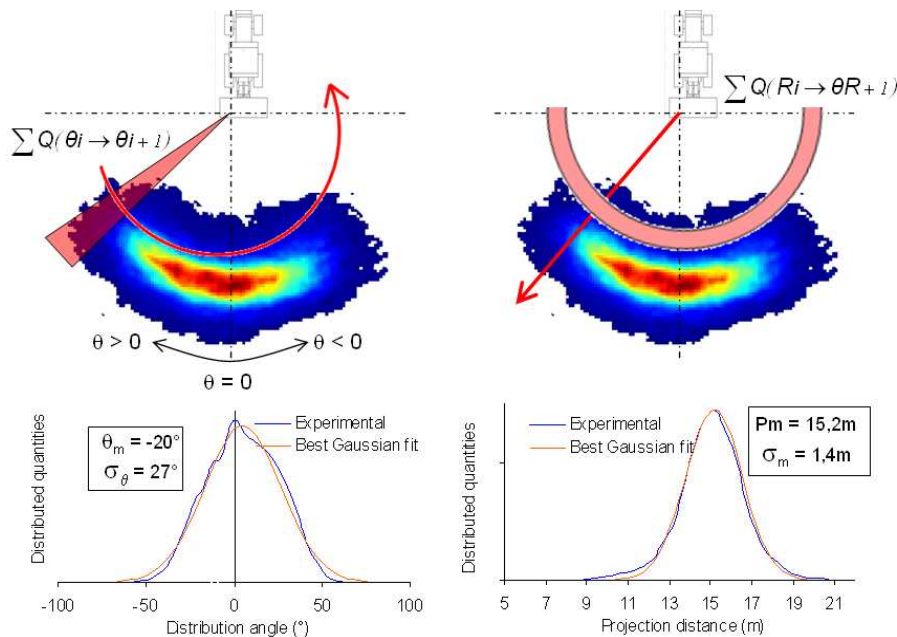


Fig. 2: Specific analysis realised on the 3D spread pattern measured: Angular and Radial distribution around the disc axis. Experimental values are extracted, as well as the best Gaussian fit, with there driven factors (mean values and standard deviations).

Based on initial works of Colin or Olieslagers, we assume that each vane of the disc distributes fertiliser on the ground according to a Gaussian distribution. The program expresses the measured spread pattern in the disc repair, so that it's possible to obtain the fertiliser distributed densities according to their polar coordinates (R , θ). Then it becomes possible to compute consecutively the angular distribution and the radial distribution (Fig. 2), from an experimental point of view. Then, best Gaussian fitting can automatically be computed to obtain in each case the mean value and its standard deviation [(P_m, σ_p) , $(\theta_m, \sigma_\theta)$].

In a very short time, these four determinants are obtained, regarding the mechanical spreading characteristics.

Using simple spreading configurations where the mechanical studied parameters are each time single, it's possible to obtain experimental laws according to an experimental reality, perfectly adapted to the spreader to model.

Fig. 3 illustrates the technique: based on four different measurements obtained with four different lengths of vane, the variation laws for the parameters P_m and θ_m are deduced. Here, a first order law can fit correctly data, but it can be necessary to use more complex laws regarding the problem, the fertiliser ... The experimental tests number to perform depends on the problem complexity.

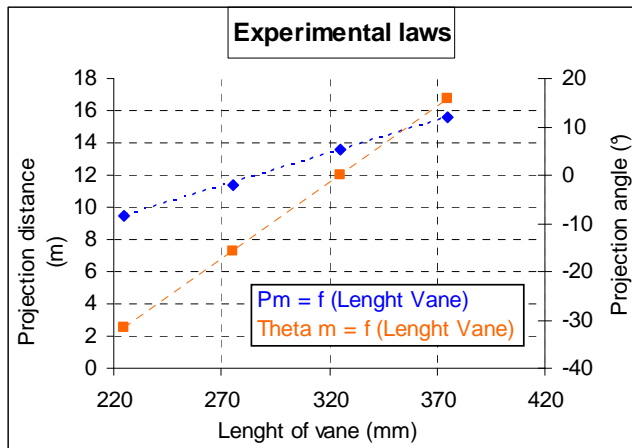


Fig. 3: Experimental laws obtained using four different measurements. Projection distance and angle are here expressed regarding the length of vane, and fitted using a first order law.

2.2. Robustness of the C.V. curves:

Problem statement

Even if an important issue is to obtain the best C.V. (lowest distribution heterogeneity) as possible, a particular point was to keep the spreading results as robust as possible in different spreading configurations. It means the spreading defaults induced by tramlines variability must be as low as possible.

The Fig. 4 illustrates the problem. Both cases (right and left) of applications are obtained with a spreader correctly set for a 24m working width (C.V. = 4%). The spreading is performed along two trajectories in the field, and with a regularly increasing space between them, from 20m to 30m. The global fertiliser amount is the same in both cases. Nevertheless, under and over applications are significantly different in both cases: on the left, defaults are in the range [80% - 120%] while they are in the range [20% - 150% or more] on the right. As it's commonly known, the explanation comes from the geometric shape of the transverse distribution curve, which is quite triangular on the left while it is trapezoidal on the right. Over or under applications are diluted on all the area in the first case, but concentrated on limited area in the second case.

Objectives of the manufacturer are also to achieve the more as possible triangular curves in a great range of application cases.

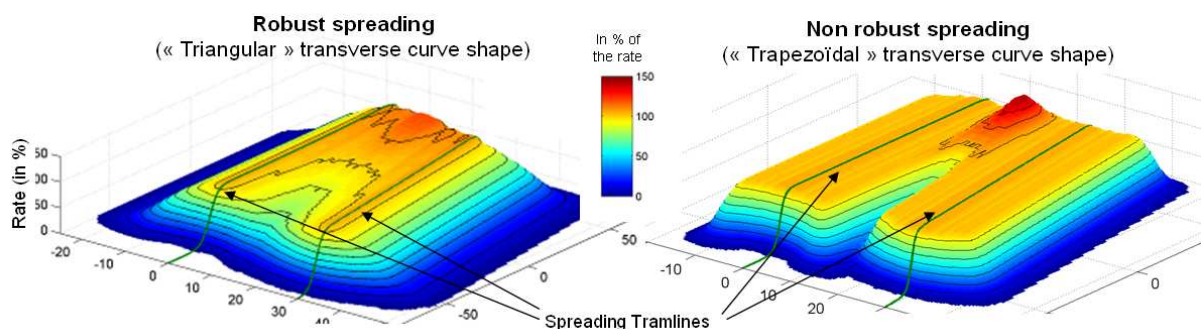


Fig. 4: Example of default applications in the field when tramlines aren't regularly spaced, and regarding two different application parameters.

This robustness parameter is appreciated regarding two different criteria:

- The first one is the ratio $\frac{2.Ww}{Tw}$ (Ww is the working width, and Tw is the Throwing width).

When this ratio is equal to 1, the distribution area is in keeping with the wanted working width. When the value is largely superior to 1, it guarantees some significant risks of under and over applications as soon as tramline variations occur.

- The second one is adapted from a criteria introduced by Kweon and Grift (2006). It calculates the ratio between the C.V. integral curve of the measured test around the desired Ww and the C.V. integral curve for a perfect triangular distribution: $\frac{\int C.V. Tested}{\int C.V. Triangle}$ (expressed

in %) (Fig. 5). This criteria is very sensible, with a range of practical results around [100% – 2500%]. The greater is this ratio, the more the transverse curve will be sensible to the tramline space variations.

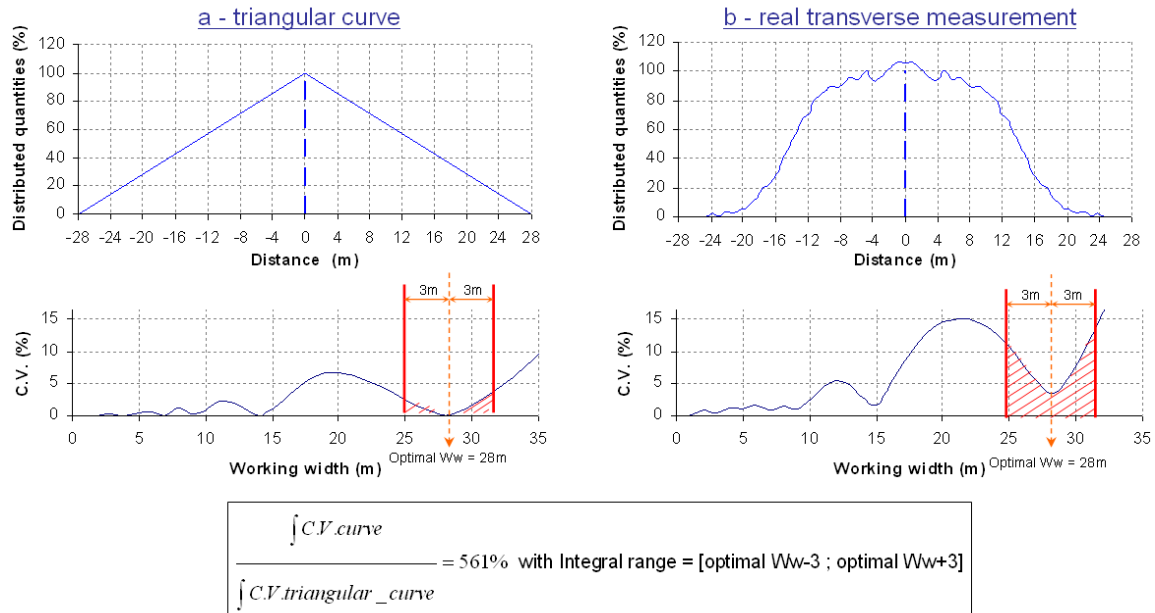


Fig. 5: Calculation illustration of the second robustness criteria.

Different discs: an obligation

The projection distance obtained with a spreading configuration (disc, fertiliser ...) allows the fertiliser distribution on a determined area and throwing width. According to the above explanations, the projection distance must increase in the same time the wanted working width increases.

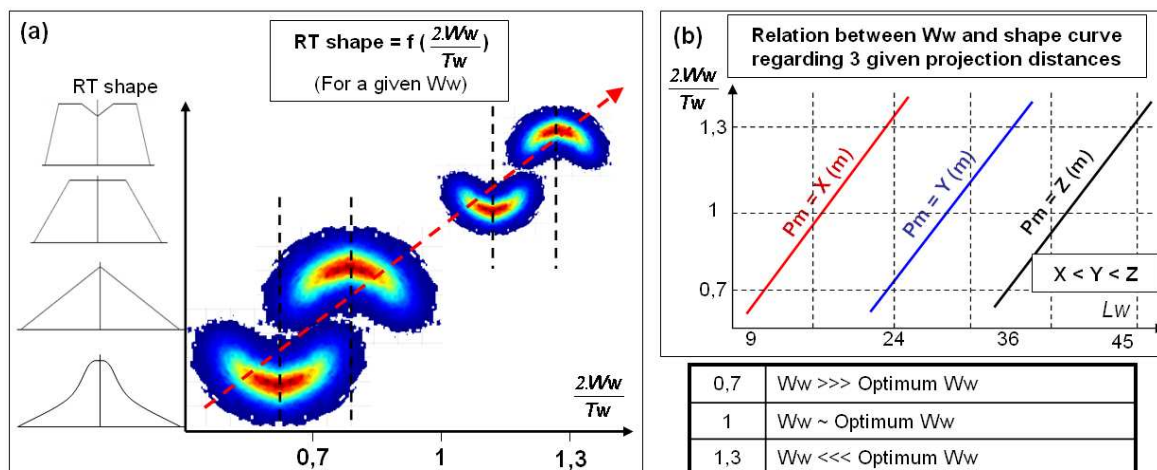


Fig. 6: Working widths, spread pattern area, projection distance induced and number of discs: technical limitations.

We consider an angular drop zone variation of the fertiliser on the disc which is a known setting to adjust the working width. With a mean value of 12m for example (the exact value

isn't an absolute correct value because it depends on numerous other parameters), it'll be possible to spread correctly between 9 and 24m, using different angular positions for the 3D spread pattern. An angular position near 0° (regarding the opposite of the travel axis displacement) allows optimised spreading around 9m while an angle of 35 or 40° allows 24m. The corresponding curves will pass from the triangular shape (Ww=9m) to the trapezoidal one (Ww=24m), and the robustness will be good at 9m, and bad at 24m. More extreme angular positions for the 3D spread pattern aren't possible for this type of use, because of very bad shape curves obtained (M shape ...).

A given mean projection distance also induces a given range of possible working widths, whatever the way setting chosen. Wider performances can't also be obtained without greater mean projection distances. It can be reached, for example, using longer vanes. Each disc of a same spreader will also be designed to work a range of working width, as shown on Fig. 6.

Regarding the ratio $\frac{2.Ww}{Tw}$, and the explanations given in the first part of this paragraph, an

almost direct relation can be established with the transversal curve shape (Fig. 6-a). Progressively increasing the spread pattern angle position regarding the axis displacement, a same initial spread pattern will allow working at different working widths. The transverse curve will pass from the "Gaussian" shape (ratio largely inferior to 1, spread pattern too large to work correctly at the given Ww) to the "triangular" shape (ratio around 1, good correspondence between the spread pattern and the wanted Ww), and finally, to the "rectangular" shape - extremely the "M shape" - (ratio largely superior to 1, Ww too important for the given spread pattern).

Finally, some working widths (Ww) can correctly be spread with only one disc, while other can be spread using 2 different discs (Fig. 6-b). In this case, C.V. can be the same whatever the used disc, while the robustness cannot. For example, a working width of 36m Ww can be obtained using the blue configuration ($P_m = Y$) or the black one ($P_m = Z$). Using the second configuration (black one) induces a triangular shape for 36m where the blue one induces a rectangular or M shape.

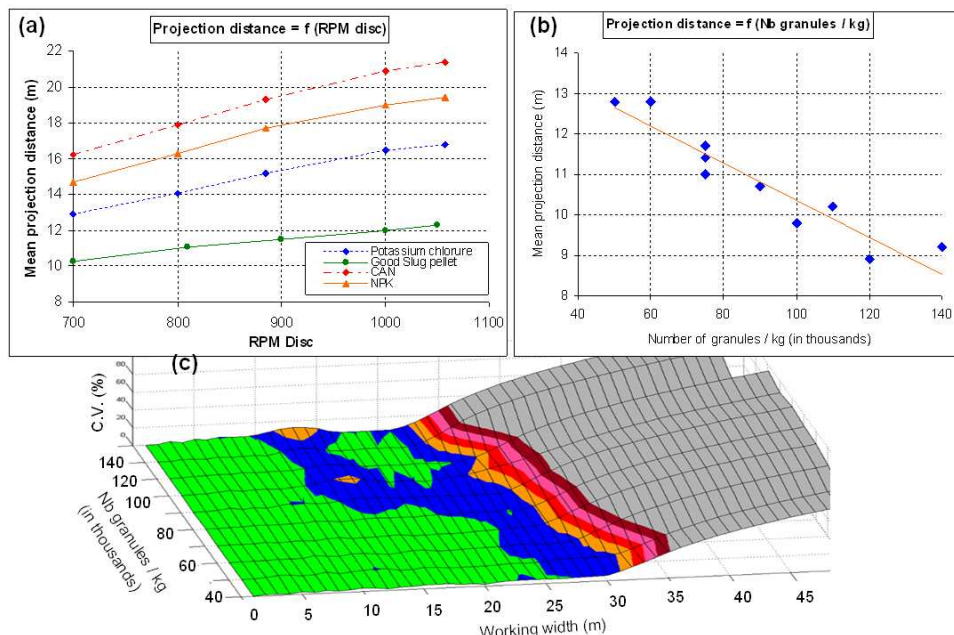


Fig. 7: Product ballistic performances (a), relation with granule physical properties (b) and consequences on their spreadability (c).

In addition, each fertiliser has its own physical characteristics, which explain finally its "spreadability" (spreading ability). Fig. 7-a shows significant ballistic performances differences for various fertilisers. For each of the initial fertiliser velocities at the output of the disc, some fertilisers present greater capabilities to reach important P_m values. The mean

diameter and its standard deviation, the density, the shape and roughness... are determinant parameters to explain these differences.

Using slug pellets, which present relatively small standard deviation around the density 0,75, a direct relation can be established between the obtained P_m value and the size of the particles: the more the size increases, the more P_m increases (Fig. 7-b). Computing all the setting possibilities for a double disc spreader, the best performances for each Ww between 2 and 50m are extracted. These best performances are reported on Fig. 7-c, after a classification on the particle sizes. Crossing the different informations, it can be concluded to a clear relationship between P_m and the spreadability: when P_m increases, the range of correct possible Ww (allowing C.V. < 15%) also increases.

The design of a new disc will also need to take into account all these various parameters, from the mechanical device to the physical fertiliser characteristics, in order to find the best set of vane, allowing a correct range of spreading performances with all the fertilisers, with the maximum of robustness...

2.3. Virtual development before the real practical development and the validation

Based on all these experimental knowledges obtained using 3D spread pattern, a software can be developed (Fig. 8).

It allows performing, without any new tests, some simulations to find, for example, the best P_m value to reach by each vane, the best associated spread pattern angular positions ..., regarding the range of desired Ww and the variability of spreading fertilisers. It represents, for manufacturers, real time and money saving, without any fertiliser use and recycling...

The design can also be performed directly by the manufacturer, according to the chosen specifications to achieve. Global performances can be predict and finely adjusted by this way.

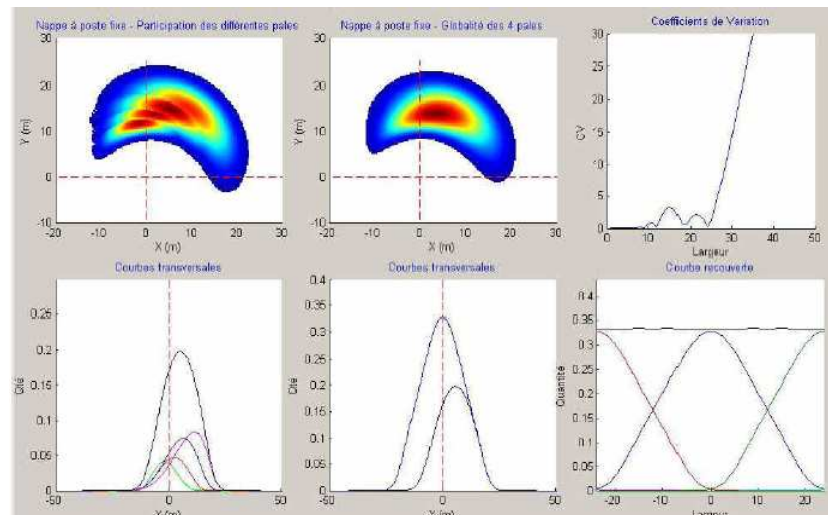


Fig. 8: Virtual assistance to the development, using experimental laws obtained from the 3D spread pattern tests, and using computer simulations.

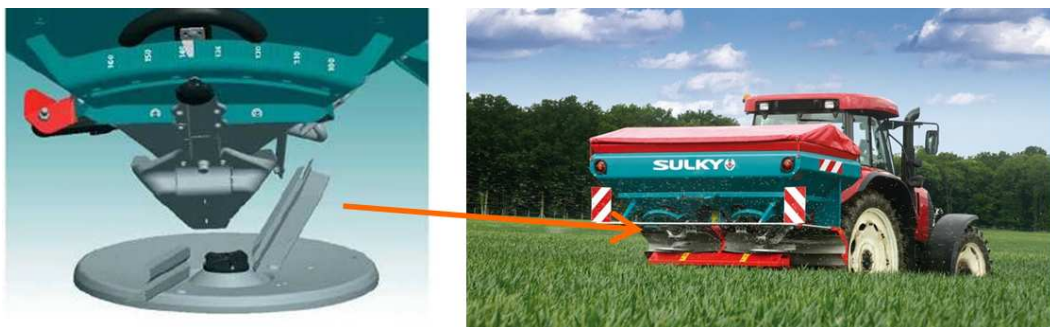


Fig. 9: Computed Aided Design (CAD) of the new spreader device, performed directly by the manufacturer.

Using the obtained requirements, the manufacturer can draw the new mechanical layout using CAD (Computed Aided Design) (Fig. 9).

3. Results

Performing different experimental tests on the CEMIB and extracting the valuable information as described in paragraph 1, then taking into account all the technical aspects and limitations, and finally using the conception method (simulator), three different discs were developed and positioned on the X Range SULKY spreader: the 12-28, the 24-36 and the 32-44 (each time, the number represent the range of Ww of the considered disc). An angular drop zone setting device was placed and optimized from the initial SULKY system (delivery chute), allowing Ww setting from the tractor cab.

3.2. Main field spreading results

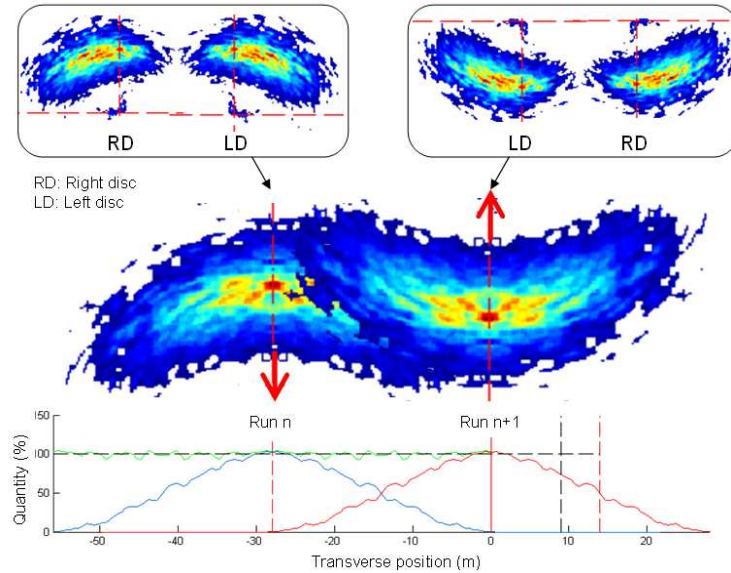


Fig. 10: Example of spread pattern obtained in main field configuration.

Results obtained for the disc 24-36 and a fertiliser of medium quality are illustrated on Fig. 10. An adapted P_m value (around 17,5m here with $\sigma_p = 3m$), coupled with a good overlapping of the distributed fertiliser densities by each vane, allow obtaining good result for the overlapped transverse curve with a very good C.V. value (around 4% at 28m).

The specific chosen arrangement leads also to robust triangular transversal curves ($\frac{2.Ww}{Tw}=0,9$ and $\frac{\int C.V. Tested}{\int C.V. Triangle} = 280\%$), in the same time each of the discs spread predominantly each side of the run.

3.2. Border spreading results

Researches to obtain main field triangular robust curves lead to a significant problem for border spreading. As it can be seen on the transverse curve of Fig. 10, non negligible fertiliser quantities should be spread out of the field if nothing was changed on the distribution device (the global amount at the right of the dotted red line). In the same time, the quantities distributed in the border distance shouldn't be 100%. Specific devices must also be developed.

In border spreading configuration, at the opposite of main field one, both discs must work differently. One must spread the needed complement to the previous run, while the second must be designed in order to avoid fertiliser distribution out of the field, and keep this fertiliser regularly distributed into the border distance.

SULKY decided to develop an innovative solution, patented (Leveillé and Clochard, 2009). The objective is to decrease the standard deviation of the projected distribution, and to correctly place the spread pattern relatively to the travel axis displacement.

As it's illustrated on the Fig. 11, the distribution device which guides the fertiliser from the hopper to the disc can be set differently regarding the wanted configuration.

For main field spreading, the fertiliser is guided to the short and the long vane: the obtained spread pattern is large, with important standard deviation and with a spread pattern angle globally placed between 15 and 30° (Fig. 11-a).

For border applications, the fertiliser is guided to the short vane and the curved short one: P_m and σ_p are also less important, adapted to the desired border width. The spread pattern angle position is also advanced in the travel direction (Fig. 11-b).

Both requirement of the EN13739 standard can be reached (YOS or EOS), using more or less important proportions of the fertiliser quantities spread by each vanes.

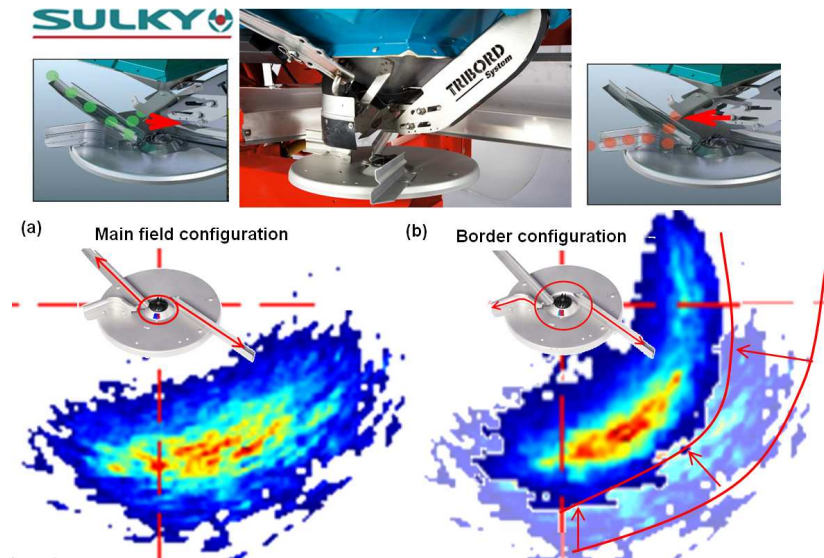


Fig. 11: Spreading device developed by SULKY for main field and border spreading.

The fig. 12 illustrates the results which are obtained with the Tribord system, satisfying the different requirements of the standard on each point. Mechanically easy to drive (small electric motor), it's a compact solution, for which developments has been accelerated by the 3D spread pattern knowledges.

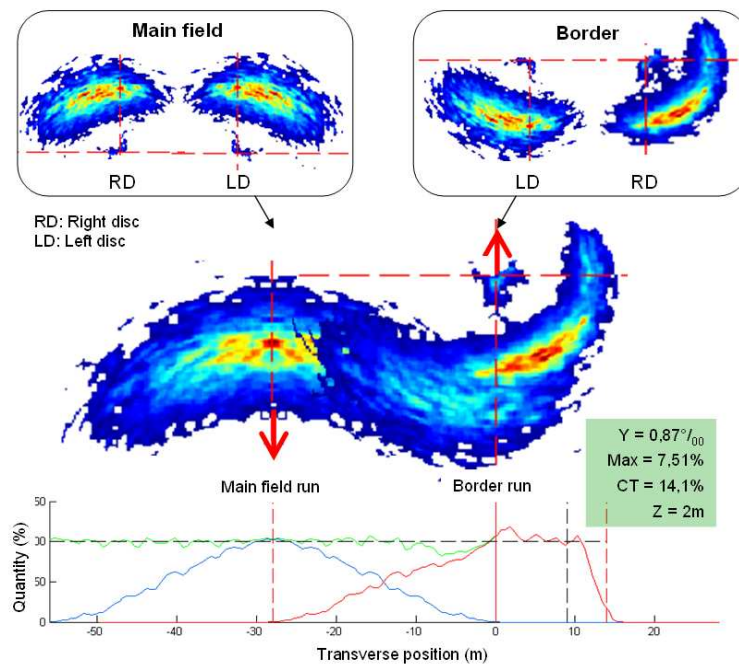


Fig. 12: Results obtained in border spreading configuration.

4. Conclusion

Using real and practical examples, main advantages of the use of the information enclosed in a 3D spread pattern correctly measured has been highlighted. In particular, the information relative to the spatial distribution has been explained, using mathematical and objective values $[(P_m, \sigma_p), (\theta_m, \sigma_\theta)]$. In addition to other classical curves (transverse, C.V. ...) and using specified quality distribution criteria, these synthetic informations are used in order to predict distribution compartments and to design spreading devices more scientifically, in a global goal to be more environmentally friendly. All the information are also used to take into account physical and technical limits, particularly considering from the design beginning all the linked problems, like robustness evaluation of the device...

The X Range spreader from the French manufacturer SULKY has been the support to illustrate the results which can be obtained, in relation with the distribution quality reached in both case of main field and border applications.

It's also an example of collaboration between the research world (new method to measure, to simulate, to understand ...) and the necessary transfer to the application world, where all concepts have to be adapted.

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