Impact of centrifugal spreaders tilt and side-tilt angles on fertilizer spreading: potential use as control variables

E.M. Abbou-ou-cherif[1], E. Piron[2,*], A.Chateauneuf[2.5], D.Miclet[1], R.Lenain[3], J.Koko[4]
[1]IRSTEA, Centre de Clermont-Ferrand, Les Palaquins, F-03150 Montoldre, France
[2] Université Blaise Pascal, Institut Pascal, BP 10448, F-63000 Clermont-Ferrand, France
[3] IRSTEA, Centre de Clermont-Ferrand, Avenue Blaise Pascal, CS 20085, Aubière, France
[4]LIMOS, Université Blaise Pascal, CNRS UMR 6158 ISIMA, BP 10125, 63177 Aubière, France
[5]CNRS, UMR 6602, Institut Pascal, F-63171 Aubière, France

**emmanuel.piron@irstea.fr*

Keywords: Fertilizer spreading, Control, Field disturbances, Uniformity.

Abstract: The uniformity of spread patterns is difficult to ensure in the presence of non-flat fields disturbances. In order to investigate the relevance of developing control devices intended to address this issue, disturbances on simple cases of slope and side-slope are assessed. For this purpose, single spread patterns are simulated on both cases and comparisons are made with the range of particles on a flat field. Then, other simulations are carried out while the spreader is put in configurations with tilt and side-tilt. The obtained results in the form of displacement fields show that the non-flat fields lead to a non-uniform skewing of spread patterns characterized by varying magnitudes and directions of displacements. When the spreader is set with tilt and side-tilt, a decrease in the magnitudes of displacement is observed. In addition, the control values of these angles are found smaller than the degrees of the field inclination. Thus, a control strategy is needed as well as a dynamic on-the-field simulation model that will help investigate the effects of disturbances and control on global spread patterns.

1 INTRODUCTION

A key challenge of precision agriculture is mineral fertilizer spreading. The latter raises both economic and environmental issues when the spread pattern is not uniform, i.e. presenting over-application or under-application areas. Today's most advanced centrifugal fertilizer spreaders incorporate some control devices like the VRT (Variable Rate Technology) and use GPS information which allows them to achieve site-specific application. While such devices are proved to optimize crop yields on flat fields, the result could be random because of some disruptive factors due to non-flat fields.

Yet, few studies dealt with the influence of the field elevation and no model was developed for this purpose allowing the simulation of spreading on non-flat-fields. Experimentally, Parish (2003) studied the effects of the angular error in the orientation of a centrifugal spreader with respect to a flat field. He found that errors as small as 5° front to rear could lead to a significant distortion of the spread pattern. Yildrim (2008) made a similar study but he used a twin-disc spreader and focused on the side to side angular error. He observed that distribution patterns are heavily skewed weather to the right or to the left which implies an increase of the CV. These results demonstrate that any setting intended for fertilizer spreading on a flat field could lead to significant uniformity perturbations of the global spread pattern on a non-flat field. Simulation could be a fast and a non-expensive mean to gain a thorough knowledge about the effects of non-flat fields on the spread pattern and help developing active control devices to correct them. However, existing models not only consider one particle a time, but also they do not take into account the field elevation. The existing models can be on one hand fully analytical (Dintwa et al. (2004),Villette et al. (2005) ,Van Liedekerke et al. (2009)) taking into account a particle dynamic from their drop from the hopper on the disc to its landing on a flat field. On

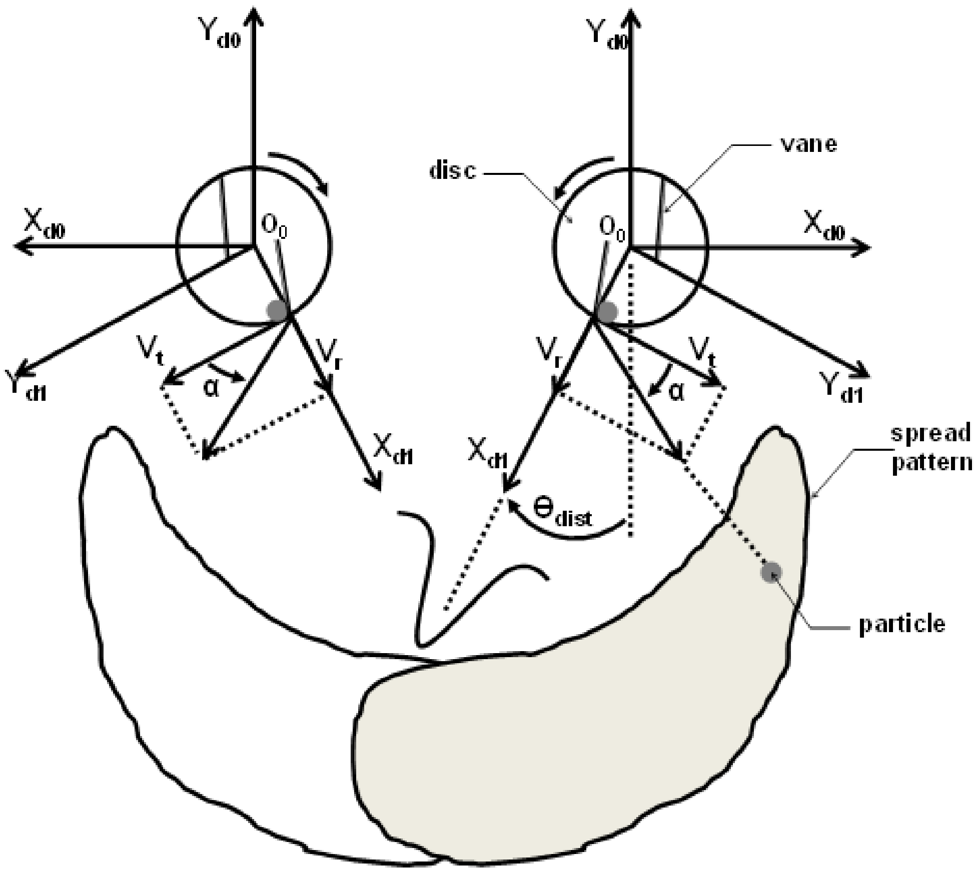

Figure 1: representation of a twin-disc spreader top view and a spread pattern resulting from the overlapping of two single spread patterns. α, the horizontal outlet angle used in the calculation of the initial output velocities; θ_{dist}, the horizontal distribution angle.

the other hand, some models called hybrid (Reumers et al. (2003),Villette et al. (2008)) only consider the ballistic flight phase which is then initialized with some measured input data. The hybrid approach is widely used due to its main advantage that is setting aside the complex modelling of particles dynamic on the spinning disc while taking them into account in the input angular distributions.

Designing new control devices meant to manage non-flat fields disturbances requires up-stream to develop a reliable simulation model of global spread pattern that allows to gain a thorough understanding on how they are effected and also to test various control strategies. In order to show the relevance of this approach on which future studies are going to be based, simple simulations using a modified hybrid approach technique are carried out on simple cases of non-flat fields (slope and side-slope) and also with the deliberate presence of tilt and side-tilt angles of the spreader. The latter angles are investigated as potential control variables that may be varied according to the encountered situation in order to ensure uniform spread patterns.

2 METHODS

The study of simple cases of non-flat fields such as slope and side-slope does not require a complex model that integrates the motion of the tractor. This stems from the fact that regular non-flat fields in the absence of other disturbances can give rise to a skewing in a single spread pattern that is duplicated along the paths of the tractor. Thus, simulations in this study are carried out in single spread patterns. Moreover, the hybrid approach technique is used. The latter allows to easily taking into account the inclination of the tractor due to the slope or side slope by modifying the initial conditions of ballistic flights. The latter are given for distinct particles only by the ballistic flight model in Eq.(1) that was

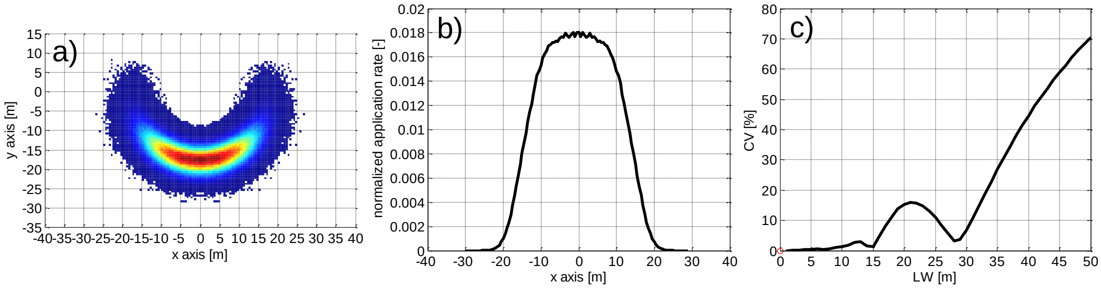

Figure 2 : single spread pattern obtained on a flat field (a) and its transverse application rate curve (b) and CV (c)

proposed by Mennel and Reece (1963) and considers only the drag force and gravity.

$$\begin{cases} \frac{dV_x}{dt} = -\frac{1}{2}.\frac{\rho_a.C_x.S_p}{m}.|V|.V_x \\ \frac{dV_y}{dt} = -\frac{1}{2}.\frac{\rho_a.C_x.S_p}{m}.|V|.V_y \\ \frac{dV_z}{dt} = -\frac{1}{2}.\frac{\rho_a.C_x.S_p}{m}.|V|.V_z - g \end{cases} \qquad (1)$$

with $\boldsymbol{\rho_a}$ is density of air, [kg.m-3]; $\mathbf{C_x}$ is the drag force coefficient of a particle; $\mathbf{S_p}$ is the projected surface area of a particle [m2]; m is the mass of a particle [Kg]; (Vx,Vy,Vz) are the components of the velocity of a particle [m.s-1].

In order to consider a flow of particles, the distributions of some of their output parameters from the disc are used to initialize ballistic flights. Three distributions are taken into account for these parameters: the horizontal outlet angle, the vertical outlet angle and the fertilizer diameter. These parameters not only allow calculating the magnitudes of the outlet velocities from the disc according to the equation of Villette et al. (2008) but their directions as well. A representation of the horizontal parameters involved in the hybrid approach simulation in addition to the principle of overlapping of two single spread patterns of a twin-disc spreader is given in Figure 1. The values characterizing the distribution of the fertilizer NPK given by Villette et al. (2013) are used. Once the necessary parameters are known for each particle and the output velocities calculated, simple geometrical transformations of the latter are done in order to take into account the field inclination whether in the case of slope or side-slope. Thus, accurate ballistic flights are derived; their intersection with inclined fields give spread patterns that are assumed to be skewed in comparison with those in the case of flat fields.

Intersection between ballistic flights and fields are given by 3D points with their mass. However, in order to obtain a 2D representation of spread patterns some transformations are needed. Simple projections on a horizontal surface are not accurate since they can lead to distortion and thus to a bad estimation of the real range of particles in the field. For this reason, curvilinear lengths are calculated. In a simple case of slope and side-slope, the curvilinear lengths can be derived easily through Pythagora's theorem. Thus, considering a landing position of a particle given by the 3D point (x,y,z), two curvilinear lengths are calculated by $L_x = \sqrt{x^2 + z^2}$ and $L_y = \sqrt{y^2 + z^2}$. The latter are used to have the 2D plot of single spread patterns on non-flat fields that are to be compared to the single spread pattern on a flat field presented in Figure 4.a. The spread pattern on a flat field is characterized by a transverse application rate that is Gaussian-shaped (Figure 4.b) which means it is robust according to Grift (2000), in addition to the CV at the optimum working width that is inferior to 5% (Figure 4.c).

3 RESULTS AND DISCUSSION

In order to highlight disturbances that occur due to non-flat fields, a high degree of slope is considered. Thus, simulations are carried out in a first case with 20° of slope and in a second case with 20° of side-slope. Visual comparisons with the spread pattern of Figure 4.a obtained on a flat field do not allow making any observation. For this reason, displacement fields of particles are calculated which allows not only to know exactly the magnitudes of displacements but also their directions. Displacement fields are represented by vectors defined by two-points given by the initial positions of particles on a flat field and their new positions on non-flat fields. The magnitudes represent the norm of the latter vectors.

The displacement field relative to a 20° slope represented in Figure 3.a and the one relative to a

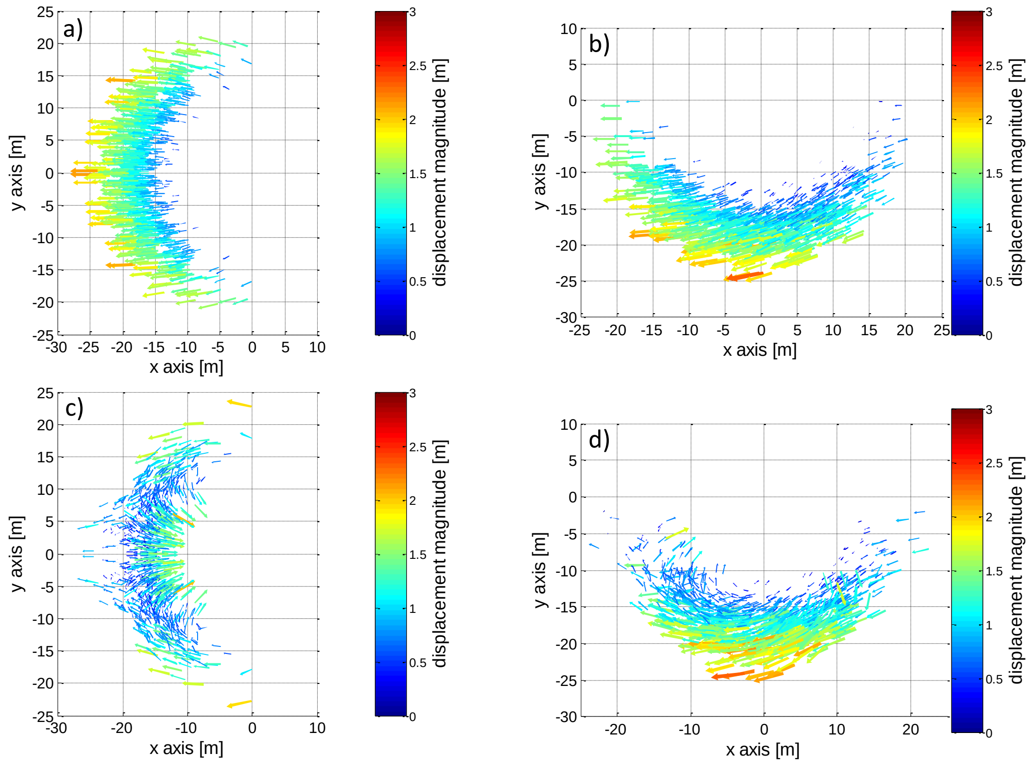

Figure 3 : displacement fields of spread patterns due to 20° slope (a), 20° side-slope (b), 20° slope with 2° Tilt for the discs (c) and 20° side-slope with 2° of side-tilt for the left disc only (d)

20° side-slope represented in Figure 3.b show that the spread patterns are not affected uniformly with displacements varying from 0m up to 2.5m. Also, the directions of displacements are not always as expected, parallel to the travel direction of the tractor in the case of slope and perpendicular to it in the case of side-slope. Since the field is regular in both cases, it leads to the same change of the vertical outlet angle of particles from the disc. Thus, the observed variability stems from another factor that affects not the initial conditions but ballistic flights themselves. In the absence of any disturbance factor such as wind, an explanation can be given by the gravity effect. The latter acts in the case of a positive slope such as ballistic flights of particles are accelerated with bigger magnitudes of deviations when particles leave the disc with bigger outlet angles. This explains the fact that the highest magnitudes are obtained at higher radial positions of particles at position near the travel direction of the tractor Figure 3.a. A similar explanation can be given for the observations in the case of side-slope (Figure 3.b), yet higher magnitudes of displacement affect the left side of the spread patter. This is due to the fact that gravity does not affect equally particles coming from the left and right disc in this case, the

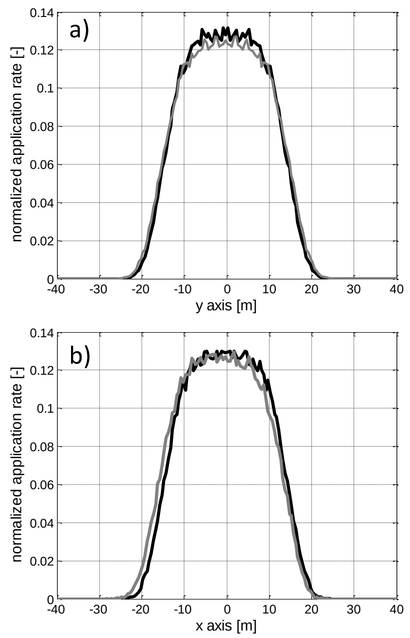

Figure 4 : transverse application rate curves of the spread pattern obtained on a flat field (black) superposed with the one on slope (a) and on side-slope (b) (gray).

first ones being accelerated while the second ones are decelerated. This difference is also translated into a different change in the shape of spread patterns that can be confirmed by the curves of their transverse application rate. In the case of slope (Figure 4.a), the spread pattern is scarcely skewed to the edges but with under-application in the middle while in the case of side-slope, the spread pattern is skewed to the left. Other simulations allow observing that even smaller changes affect the shape of the spread pattern in the case of a negative slope, while the spread pattern is symmetrically skewed to the right in the case of a positive side-slope.

The previous results imply that a different control is necessary according to the encountered situation in order to ensure a uniform spreading. Parish (2003) and Yildrim (2008) in their investigation of the effects of an unlevelled spreader with respect to the ground carried out tests in which the spreader is tilted or side-tilted. These configurations can be set thanks to some settings of the three-point linkage in twin-discs spreaders. As a consequence, their potential use meant to counteract the field inclination is investigated. Intuitively, for a positive slope and side-slope, a negative tilt angle and side-tilt angle could be set up and vice versa. For more flexibility, it is assumed that each disc can be controlled separately as represented in Figure 5. However, it was observed that the necessary angles are not equal to the degree of the field inclination. For instance, in the studied cases of 20° slope and 20° side-slope, it is found through calibration that 2° of tilt applied to both discs and 2° of side-tilt applied to the left disc only are the optimal values. The fact that the necessary corrections are too small coincides with the observations made in the transverse

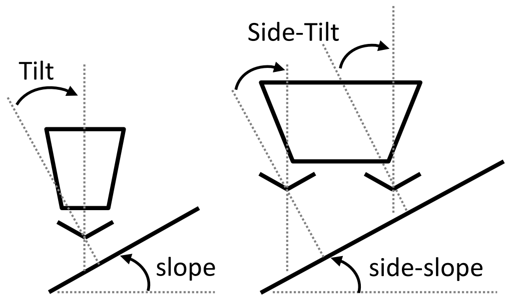

Figure 5 : representation of the tilt and side-tilt corrections applied respectively in the case of slope and side-slope

application rate curves (Figure 4) that are found skewed of less than 3m. Figure 3.c and Figure 3.d show the resulting displacement fields of particles after the application of the tilt and side-tilt corrections. It can be observed that the magnitudes of displacement in some areas of the spread patterns have decreased while in others they remain constant. This is due to the fact that the applied corrections affect mainly particles that are far from the rotation axes responsible of the tilt or side-tilt rotation of the discs. A better understanding of how the previous corrections are achieved is obtained by the analysis of the distributions of the output velocities from the disc in the case of a flat field but with the tilt and side-tilt being set up. Considering the coordinate system (X_{d0},Y_{d0},Z_{d0}) of Figure 1, the distributions represented in Figure 6 show that a tilt around X axis affects the velocity components V_y, likewise side-tilt around Y axis affects the velocity components V_x. In both cases the V_z components are

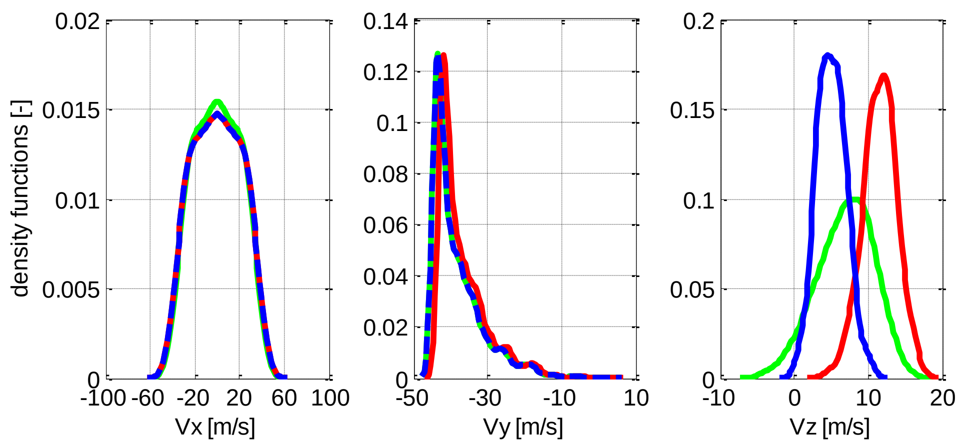

Figure 6 : distributions of particles output velocities on a flat field in the case of 0° tilt and side tilt (blue), in the case of 10° tilt around X axis (red) and 10° side-tilt around Y axis (green)

affected. However in the case of Tilt, it can be observed that the mean velocity increases and the standard deviation is scarcely changed, while in the case of side-slope both the mean and the standard deviation increase. These results imply that any correction of the discs orientation not only deviates ballistic flights but also induces an increase of the outlet velocity vertical component. As a consequence, applying an angle of correction equal to the field inclination angle does not involve necessarily returning to the initial range of particle on a flat field. Furthermore, because of the non-symmetrical spread patterns due the side-slope (Figure 3.b) and the increase of the standard deviation of the outlet velocity vertical component due to the side-tilt, a better result is obtained when each disc is controlled separately in the case of side-slope.

The simulation of global spread patterns obtained on DEMs with back and forth paths of the tractor are still necessary in order to assess the impact of the field inclination as it is in reality. This determines as well the relevance of the corrections investigated in this study. For this purpose, an ongoing work focuses on the development of a simulation model integrating the field elevation and the tractor motion. Other cases could then be investigated such non-regular fields that may lead to even higher magnitudes of disturbances.

4 CONCLUSIONS AND FUTUR WORK

Simulations of single spread patterns in the case of slope and side-slope are carried out thanks to the use of the hybrid approach. Disturbances are found affecting the spread patterns. They are characterized by non-uniform displacement fields of particles such that in the case of slope, displacement vectors are directed parallel to the travel direction of the tractor with higher magnitudes at farther position from the tractor. By contrast, in the case of side-slope, displacement vectors are directed perpendicular to the travel direction of the tractor with higher magnitudes affecting only a half-side. Yet, only a small skewing is observable in the transverse application rate curves, to the outside edges in the case of slope and to the left in the case of the positive side-slope. The latter difference implies that the resulting overlapping of the skewed spread patterns may be deteriorated leading to different disturbances in the global spread patterns. Corrections based on setting the spreader in configurations with tilt and side-tilt angles show that the magnitudes of displacement fields are decreased. However, the control angles needed are found smaller than the fields inclination degrees because of a change in the distributions of output velocities components especially the vertical one. As a consequence, carrying out dynamic on-the-field simulations is still needed and will help not only to assess disturbances due to global spread patterns but also to validate the effectiveness of control strategies.

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