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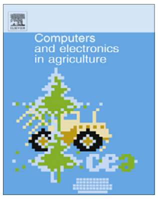

Original papers

# On-the-field simulation of fertilizer spreading: Part 2 – Uniformity investigation

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ABSTRACT

Modern centrifugal spreaders use active control devices to manage various disturbances affecting the spreading uniformity on flat fields. Yet, non-flat fields that are also likely to cause application errors, are still not taken into consideration. This was highlighted in some experimental studies, limited to the case of single spread patterns on regular non-flat fields.

In this study, overall spread patterns uniformity was investigated through simulation. The model used was presented in the paper ("On-the-field simulation of fertilizer spreading: Part 1 – Modeling"). Using computer generated DEMs (digital elevation models), several cases were investigated: regular fields were represented by a longitudinal and side slope, and irregular fields by a longitudinal and side slope break.

The results obtained were in the form of application rate maps, showing the areas of overapplication and underapplication. These areas were also characterized by the mean longitudinal and transverse application rates, which gave the application errors magnitudes. The latter were in the case of irregular fields, up to a maximum of +45%, and a minimum of −25%, around the theoretical value of 100% for a perfectly uniform area. These application errors were mainly attributable to altered ballistic flights range, caused by the difference between the tractor and spread surface inclination, and to a lesser extent, by the work of the gravity. These results allow bridging the knowledge gap around overall spread patterns uniformity on non-flat fields. They can also help in developing new active control devices.

## 1. Introduction

Mineral fertilizers represent a necessary agriculture input for plants growth and crop yield optimization. According to a study by Stewart et al. (2005), at least 30–50% of crop yield in USA and England is attributable to commercial fertilizers. However, it is also proven that mineral fertilizers have a direct link with soil acidification (Barak et al., 1997) and water systems eutrophication (Bechmann et al., 2005). Besides raising environmental issues, excessive fertilization has also a long term effect on the sustainability of the agricultural activity (Tilman et al., 2002). As a consequence, the concept of precision agriculture emerged as a means of satisfying the worldwide growing food demand (Godfray et al., 2010), while persevering the environment and future generations needs.

Control and automation are some aspects of precision agriculture. They have become heavily used in fertilizer spreading. For instance, high-end modern centrifugal spreaders use GPS and geographic information systems (GIS) with variable rate technologies (VRT), to apply optimal fertilizer rates. However, even though assuming the desired local rate is known, application errors occur due to some disturbances, like tractor guidance errors (Lawrence and Yule, 2007), parcel geometry singularities (Virin et al., 2006), and rough operating surfaces (Parish, 1991). For this reason, centrifugal spreaders performance is assessed by their ability in achieving a uniform spread pattern on theoretical parcels with homogenous fertilizer needs, regardless of the external disturbances. Spread patterns uniformity is commonly characterized by the statistical factor CV (coefficient of variation). The lower the CV is, the more uniform is the application result. Today, thanks to automatic guidance systems (Keicher and Seufert, 2000), precise driving allows accurate overlapping of the spread patterns, leading

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to a potential decrease of CV from 50 to 20% (Lawrence and Yule, 2007). Geometry singularities and boundary spreading are also handled thanks to the use of drop point and flow rate control devices, that allow adapting the shape of the spread patterns. For instance, the study of Virin et al. (2006) showed that such control actions allow keeping the local applied rates between −9% and +10% of the desired application rate, thus achieving a near-uniform overall spread pattern.

If satisfactory results of spreading uniformity can be achieved on flat fields, there is no evidence to expect the same results when centrifugal spreaders are used in other conditions. A recent experimental study of Grafton et al. (2015), pointed out that longitudinal and side slope lead to the skewing of single spread patterns. The same result was obtained by Horrocks et al. (2015), who focused on particular landforms such as humps and hollows. These results are in accordance with those of Parish (2003) and Yildrim (2008). They showed that out-of-level spreaders with an angular error as small as 5° with respect to the spread surface, imply a minimum CV value of single spread patterns above the value obtained in the level position. Considering all these results, it can be assumed that single spread patterns skewing is likely to affect the overall spread pattern uniformity. To our knowledge, the issue of overall spread patterns uniformity on both regular and irregular non-flat fields have not been tackled before. This represents a serious knowledge gap, knowing that arable fields can be found on a variety of landforms (e.g. on valley, ridge, lower slope, middle slope, upper slope and flat slope, according to Chendes et al. (2008)). The presence of slope may be mainly determined by the geographical location of farms. For the field regularity, farms size is also an important parameter. Recent data analysis in high income countries, showed that the average farm size have increased from 20 to 30 ha from 1960 to 2000 (Lowder et al., 2016), and that farms larger than 20 ha operate up to 70% of the total land (Adamopoulos and Restuccia, 2014). As a consequence, large and average size fields are likely to cover more than one landform, thus they are not necessarily flat or regular.

The purpose of this study is to help bridging the knowledge gap around overall spread patterns uniformity, both in the case of regular and irregular non-flat fields. This means providing for the first time, overapplication and underapplication orders of magnitude in percentage, and also explaining how they take place. As it is difficult to use measurement to obtain field application maps, by the means of the collecting tray method, the study was conducted using simulation. Measurement would require a huge number of collecting trays to cover entire fields, which is impossible and suited only for single spread patterns. The model used was presented in the paper ("On-the-field simulation of fertilizer spreading: Part 1 – modeling"). It was based on a hybrid approach of modeling that allows deriving the ballistic flights initial conditions and their updating along the tractor trajectory. Using a limited number of simulations, uniformity was investigated in theoretical but yet realistic situations. This included for regular fields, longitudinal slope and side slope, and for irregular fields, longitudinal and side slope break. The results obtained are of importance to manufactures, as on the one hand, they show if overall spread patterns uniformity is affected enough to consider new control devices. On-the-other hand, they can help in designing the control laws, based on the field application maps provided in this study.

## 2. Handling of on-the-field simulation

The output of all the simulations is always in the form of an overall spread pattern resulting from the overlapping on the field, of single spread patterns of a given shape. An overall spread pattern must be already uniform on a flat field. Hence, application errors obtained on non-flat fields, cannot be altered by application errors due to a bad overlapping. For this reason, the first step of this study focused on choosing the most robust shape of the single spread pattern to be used as the core of on-the-field simulation model.

Simulation offers the advantage of investigating uniformity on large fields, rapidly and inexpensively. However, the results obtained have to be representative of application errors due to field disturbances encountered in real-world spreading. For this reason, the second step focused on choosing DEMs (digital elevation models) of theoretical but yet realistic arable fields.

### 2.1. Choice of the core single spread pattern

Three basic shapes characterizing the transverse distribution of a single spread pattern were analyzed by Grift (2000): Gaussian, triangle and trapezoid. He found the Gaussian shape to be the most robust, because it is less sensitive to disturbances such as small deviations in trajectory and variations of the working width, thus resulting in a good overlapping. Olieslagers et al. (1996) affirmed as well that the Gaussian shape is preferred in fertilizer spreading, because it involves a smaller coefficient of variation (CV), which is an indicator of the spreading quality. For this reason, several simulations were conducted to derive the model parameters that enable having a single spread pattern with a Gaussian shape. The three shapes analyzed by Grift (2000) are rather theoretical. Thus, it was difficult to obtain a single spread pattern whose transverse application rate can be fitted by a Gaussian curve. Alternatively, the focus was put on having a single spread pattern with an intermediary shape between a triangle and trapezoid.

In Part 1 of this study, the model was developed and tested with non-perfectly spherical particles and discs rotating at 800 rpm. Using this model and values for its input data of the same order of magnitude, the single spread pattern of Fig. 1b was obtained. It has the desired shape, as at the optimal working width of 28.5 m where it allows overlapping, varying the model parameters led to the trapezoidal shape of Fig. 1a and triangular shape of Fig. 1c. This can be verified in Fig. 1d where the transverse application rate curves of the three single spread patterns are superposed. Passing from the intermediary shape to the trapezoidal requires shifting the particles horizontal angular distribution to the outside, decreasing the particles mean diameter, decreasing the fertilizer density and increasing the drag coefficient. By contrast, obtaining the triangular shape requires shifting the particles horizontal angular distribution to the inside, increasing the particles mean diameter, increasing the fertilizer density and decreasing the drag coefficient. Table 1 summarizes the parameter values that allowed having the three single spread patterns.

By contrast with Grift (2000) results, the triangular shape seems offering better performances as its CV is less than 10% for all the working widths below 28.5 m (Fig. 1f). However, because of the high range of particles due to this shape, up to a mean of 22 m (Fig. 1e), application errors may be excessive during on-the-field simulations. Moreover, this shape tends to be rather difficult to achieve in reality because of the fertilizer performance and spreader characteristic requirements. Therefore, the intermediary shape was retained for the sake of compromise between robustness, practicability, and realism of the single spread pattern used as the core of the simulator.

### 2.2. Characterizing the uniformity of the overall spread pattern

Field application maps were calculated using regular grids of 1 × 1 m meshes. Each mesh represents a collecting tray where a given fertilizer rate is accumulated. Since all the simulations were carried out with the same particles flow rate and tractor forward