Computers and Electronics in Agriculture 137 (2017) 115–129

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Hybrid centrifugal spreading model to study the fertiliser spatial distribution and its assessment using the transverse coefficient of variation

S. Villette [a,b,*], E. Piron [c], D. Miclet [c]

[a] Agroécologie, AgroSup Dijon, INRA, Univ. Bourgogne Franche-Comté, F-21000 Dijon, France
[b] Equipe Agroéquipements, AgroSup Dijon, BP 87999, 21079 Dijon Cedex, France
[c] IRSTEA, Les Palaquins, 03150 Montoldre, France

ARTICLE INFO

Article history:
Received 3 April 2016
Received in revised form 27 March 2017
Accepted 31 March 2017
Available online 7 April 2017

Keywords:
Centrifugal spreading
Coefficient of variation
Model
Monte Carlo
Simulation
Virtual spreader

ABSTRACT

Studying centrifugal spreading by carrying out field or in-door experiments using fertiliser collection trays is tedious and labour intensive. This is particularly true when several implementation methods need to be compared, numerous replications are required or fertiliser sample characterisation is required. To circumvent cumbersome experiments, an alternative approach consists in performing in silico studies. In order to reach this objective, a hybrid centrifugal spreading model is designed by combining theoretical fertiliser motion equations with statistical information. The use of experimental measurements to characterise fertiliser properties, outlet velocity, angular mass flow distribution and spread pattern deposition, ensure a realistic calibration of the model. Based on this model, static spread patterns and transverse distributions are computed for a virtual twin-disc spreader. The number of fertiliser granules used to compute a spread pattern is deduced from the target application rate while the granule properties and their motion parameters are randomly selected from pre-established statistical distributions. This Monte Carlo process reproduces the random variability of fertiliser spread pattern depositions. Using this model, simulations demonstrate the mean and standard deviation of CV value decrease with the application rate. The CV mean value also decreases with the collection tray surface, while the standard deviation decreases with the collection tray length. Mathematical relationships are deduced from simulation results to express the mean and standard deviation of the CV as functions of the application rate and collection tray surface or length. The simulation model is also used to compare spreader test methods and study the influence of some fertiliser particles properties on the transverse distribution.

1. Introduction

In agriculture, the objective of mineral fertiliser supplies is to provide the right rate of nutrients to cultivated plants. Because of their low cost and high productivity, centrifugal spreaders are widely used for this application aiming to spread fertiliser at a target rate with an acceptable uniformity in the field. For 50 years, several works have demonstrated the negative effects of non-uniform spatial distributions concerning environmental impacts (Tissot et al., 2002) and yield or economical losses (Horrell et al., 1999; Jensen and Pesek, 1962; Miller et al., 2009; Richards and Hobson, 2013; Søgaard and Kierkegaard, 1994; Tissot et al., 1999). For the same decades, numerous works have been devoted to the measurement of fertiliser distributions, the assessment of distribution quality and the understanding of spread patterns. Throughout the world, transverse tray tests are traditionally performed to measure the spreading uniformity according to various standards such as: ISO Standard 5690/1 (1985), ASAE Standards S341.2 (1999); EN 13739-2 (2003); Spreadmark code of practice (New Zealand Fertiliser Quality Council (2015)) or ACCU Spread (Australian Fertiliser Services Association, 2001). The experimental transverse distribution is then used to compute the coefficient of variation CV after overlapping. This CV value is used to quantify the spreading quality, define the appropriate swath spacing according to the fertiliser and spreader setting, and thus certify the spreader bout width.

Some studies have addressed the comparison of transverse distribution measurement methods. Several works investigated the influence of the collection systems. Parish (1986) compared twelve collection methods in laboratory conditions using a

---

* Corresponding author at: Agroécologie, AgroSup Dijon, INRA, Univ. Bourgogne Franche-Comté, F-21000 Dijon, France.

E-mail address: sylvain.villette@agrosupdijon.fr (S. Villette).

http://dx.doi.org/10.1016/j.compag.2017.03.023
0168-1699/

Nomenclature

a	regression parameter
A_p	particle frontal area, m^2
b	regression parameter
c	regression parameter
C_d	drag coefficient
CV	transverse coefficient of variation, %
CV$_{\mathrm{geom}}$	geometrical component of the CV, %
CV_k	value of the CV obtained when the collection tray width is w_k, %
D	continuous random variable, m
d_p	fertiliser granule diameter, m
d_{pi}	diameter of the ith fertiliser granule, m
$F_D(d_p)$	cumulative frequency function of the granule diameter
$f_D(d_p)$	probability density function of the granule diameter
g	acceleration due to gravity, m s^{-2}
$G_D(d_p)$	cumulative mass distribution function of the granule diameter
$G_M(\theta_{vane})$	cumulative mass flow distribution with respect to the vane location
$g_M(\theta_{vane})$	mass flow distribution with respect to the vane location
h_{vane}	height of the outer extremity of the vane, m
K	constant, m^3
K_a	aerodynamic coefficient, m^{-1}
l_{tray}	length of the collection tray, m
L_w	swath spacing, m
m	particle mass, kg
$m(d_p)$	mass of a granule of diameter d_p, kg
m_i	mass of the ith fertiliser granule, kg
m_{tot}	total mass of fertiliser ejected by the two discs of the virtual spreader, kg
n_{disc}	number of granules ejected by one disc of the virtual spreader
$(\mathrm{O}, \boldsymbol{i}, \boldsymbol{j}, \boldsymbol{k})$	Cartesian frame centred on the disc centre, with $\boldsymbol{j}$ oriented in the travel direction
q_t	target application rate, kg/ha
q_f	in-field target rate, kg/ha
r	Pearson correlation coefficient
r_{vane}	radius of the vane, m
s_{disc}	distance between the two disc axles of the virtual spreader, m
t	time, s
v_H	horizontal component of the outlet velocity, m s^{-1}
v_{out}	outlet velocity, m s^{-1}
(vx, vy, vz)	velocity components of the granule during the ballistic flight, m
$(vx_{out}, vy_{out}, vz_{out})$	components of the outlet velocity, m s^{-1}
w_k	width of the collection trays
(x, y, z)	coordinates of the granule, m
$(x_{out}, y_{out}, z_{out})$	coordinates of the granule when it leaves the vane, m
α_{lv}	pitch angle of the vane, °
α_{set}	setting angle of the virtual spreader, °
Δl_{grid}	grid sampling interval along the travel direction, m
Δw_{grid}	grid sampling interval along the transverse direction, m
θ_{out}	horizontal outlet angle of the granule when it leaves the vane, °
θ_{traj}	horizontal orientation of the outlet velocity with respect to $\boldsymbol{i}$, °
θ_{vane}	angular location of the vane with respect to $\boldsymbol{i}$, °
μ_{CV}	mean value of the CV, %
μ_{ln}	fitting parameter of the cumulative mass distribution
$\mu\theta_{out}$	mean value of the horizontal outlet angle, °
ξ	variable of integration, m
ρ	density of the fertiliser granule, kg m^{-3}
ρ_{air}	air density, kg m^{-3}
$\sigma\theta_{out}$	standard deviation of the horizontal outlet angle, °
$\sigma\Omega_{out}$	standard deviation of the vertical outlet angle, °
σ_{CV}	standard deviation of CV, %
σ_{ln}	fitting parameter of the cumulative mass distribution
ω	rotational speed of the spinning disc, rad s^{-1}
Ω_{out}	vertical outlet angle of the granule, °
Ω_{vane}	vertical angle of the vane, °

manually-operated rotary spreader and two granular materials. The maximal effective swath width of this spreader was 4.3 m. Each test run consisted of three passes and three replications where carried out. Using the results obtained in this previous work, Parish and de Visser (1989) analysed the effect of the collection tray width on the CV value. In field, Parish et al. (1987) compared the crop response quality assessed by a horticulturist with fertiliser rates deduced from transverse distribution measurements. Three collection methods were compared using three replications for each test. All these studies demonstrated that major differences occurred in the measurement of transverse distributions depending on test methods. Therefore, the authors highlighted the importance of using the same test method for comparisons of spreader performances. Moreover regarding the low throwing distance of the spreader chosen for these studies and the low number of replications, these works illustrate the difficulties of carrying out such experiments.

To perform statistical comparisons of six international spreader tests, Jones et al. (2008) carried out a huge experimental work by using 18 transverse rows of 80 trays each. The experiments were carried out with urea, for three application rates and two replications so that 36 transverse distributions were obtained for each spreading situation. The bout width of the spreader was 15 m. Concerning the prediction of the certifiable working width, the authors concluded that the ACCU Spread test method (Australian Fertiliser Services Association, 2001) was superior to the other tested standards because it uses two rows of collector trays and multiple passes. Jones et al. (2008) concluded multiple rows of trays, multiple passes of the spreader and long trays can improve the accuracy of transverse tests.

Since the transverse distribution results from the combination of numerous parameters, it only provides a limited piece of information concerning the spread pattern. Thus, transverse tests are not efficient to study how mechanical parameters or fertiliser characteristics affect the 2D spread pattern deposition. This was illustrated by Piron and Miclet (2005) who showed that different 2D static spread patterns can yield to similar transverse patterns. Unfortunately, the measurement of the 2D static spread pattern is very tedious when a grid of collection trays is used, because of the wide size of spreader footprints and the high number of trays required to cover this area. Moreover, for indoor test, the high throwing distance of recent spreaders would require very expensive infrastructures. To circumvent these difficulties, Piron and Miclet (2005) developed a rotating test bench called CEMIB. With this method, the spreader is rotated during the spreading and a radial row of collection trays equipped with load cells records the cumulated mass of fertiliser according to the angular orientation of the spreader. The static spread pattern is then derived from