Computers and Electronics in Agriculture 147 (2018) 146–157

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

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

Original papers

Morphology characterization of irregular particles using image analysis. Application to solid inorganic fertilizers

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ARTICLE INFO

Keywords:
Fertilizer
Image analysis
Centrifugal spreader
Morphology
Distance traveled

ABSTRACT

This research deals with how to characterize the morphology of mineral fertilizers using dynamic image analysis. A machine-vision system was first developed to capture digital images of irregular particles. The vision system was designed as a mechanical assembly to generate a flow of separated grains passing in front of a camera, combined with a flash. The vision system's parameters were then calibrated and optimized – particularly in terms of image resolution, light sources and exposure time. An optimal value of 34 pixels/mm was obtained for the image resolution. Then, the system was tested and validated by imaging perfect plastic spheres of known size. Secondly, an image-processing algorithm was developed to extract geometrical and morphological information for various particles. Various shape parameters, describing the differences of a particle from a reference geometric form (e.g. a circle or ellipse), were calculated as outputs of the image-processing treatment. Statistical analysis was then applied to determine the convergence of shape parameter distributions and also the repeatability of measurements. 45 fertilizers, with grain shapes ranging from highly irregular to nearly spherical, were prepared and imaged. For all these fertilizers, the distribution of shape parameters was quantitative, representative, repeatable and reproducible using the machine-vision system developed. In order to investigate the best parameters for characterizing particle morphology, statistical correlation was applied to deduce a list of independent shape parameters. These parameters were relevant and could further be used to characterize the morphology of any fertilizer. The independent parameters thus obtained were subsequently used to detect the correlation between morphology and distance traveled by fertilizer particles thrown out by a centrifugal spreader. Experimental tests were conducted using the CEMIB device to determine fertilizer spread pattern from spinning discs. Results showed that, within the same range of size, mass density and spreader operating parameters, spherical and rounded particles traveled further than elongated and angular particles. The angularity index parameter, denoted by ANGInd (which characterizes whether a particle is rounded or angular), showed most potential application to explain the aerodynamic behavior of irregular particles spread by spinning discs.

1. Introduction

When using a centrifugal distributor for spreading fertilizers onto agricultural fields, interaction between the air and the particle surface generates mechanical force, such as drag (Olieslagers et al., 1996; Grift et al., 1997). From a physical point of view, the drag is directly affected by the morphology of the particle flying through the air (Clift et al., 1978). For that reason, a ballistic equation has been devised to model the trajectory of an individual particle, including the drag coefficient (Mennel and Reece, 1963; Grift et al., 1997; Dintwa et al., 2004; Villette et al., 2005):

$$m\boldsymbol{a} = -\frac{1}{2}C_d S\rho_f ||\boldsymbol{v}||\boldsymbol{v} + m\boldsymbol{g} \quad (1)$$

where m is the mass; $\boldsymbol{a}$ is the acceleration; C_d is the drag coefficient; $\boldsymbol{v}$ is the velocity; S is the reference surface area of the particle and ρ_f is the air density.

Grift et al. (1997) and Walker et al. (1997) correlated the drag coefficient and morphology of fertilizers by measurements of shape and independent fall-time tests. An equation of the drag coefficient was deduced as a function of particle roughness. However, no comparison between the distance traveled by fertilizers simulated using this equation and the distance actually traveled in an experiment has been

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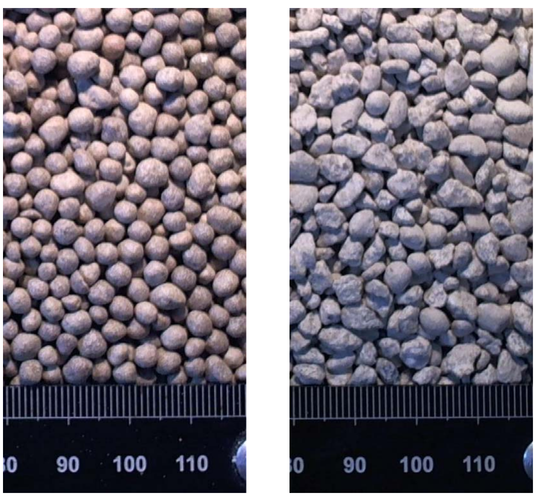
https://doi.org/10.1016/j.compag.2018.02.022
Received 18 October 2016; Received in revised form 13 June 2017; Accepted 17 February 2018

Table 1
Types, names, abbreviation, composition, sieve analysis results and mass density of the 45 fertilizers considered in this study. The Basic comp. column presents the basic composition of fertilizer (for instance, 14.16.10 means the fertilizer contains 14% of N, 16% of P_2O_5 and 10% of K_2O by weight). Second. nutr. presents the composition by weight of the secondary nutrients (for instance, 0.6.5 means the fertilizer contains 0% of CaO, 6% of MgO and 5% of SO_3 by weight). The results of sieve analysis are in mm. D_{50} presents average sieve size of fertilizer. The mass density of fertilizers is denoted by ρ.

Type	Cemib	Name	Abb.	Basic comp.	Second. nutr.	Sieve analysis	D_{50} (mm)	ρ (kg/m^3)	Proc.
N	590	CAN 27	F1	27.0.0	6.4.0	85%∈ [3.2, 5]	3.69	1681	W
	487	CAN 23	F2	23.0.0	0.0.43	77%∈ [3.2, 5]	3.66	1543	C
	575	Urea	F3	46.0.0		84%∈[2, 3.2]	2.58	1265	P
P	486	Phosphate	F4	0.18.0	36.0.0	84%∈ [2.5, 5]	3.10	2323	W
	468	Phosphate	F5	0.45.0		79%∈ [2.5, 4]	3.00	1706	W
K	444	KCl	F6	0.0.40	0.6.5	83%∈ [2.5, 5]	3.40	1996	C
NP	602	NP	F7	17.17.0	0.0.17	90%∈[2.5, 4]	3.42	1700	W
NPK	599	NPK	F8	15.15.15	0.0.7	86%∈[2.5, 4]	3.51	1675	W
	598	NPK	F9	13.10.18	0.0.14	82%∈[2.5, 4]	3.58	1746	W
	600	NPK	F10	16.17.12	0.0.8	83%∈[2.5, 4]	3.58	1664	W



(a) Fertilizer F1 (b) Fertilizer F2

Fig. 1. Samples of fertilizer particles (pictures taken at Irstea Montoldre). Details of fertilizers are given in Table 1.

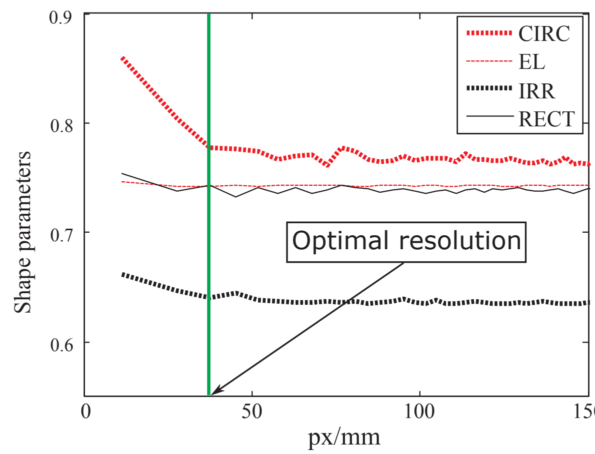
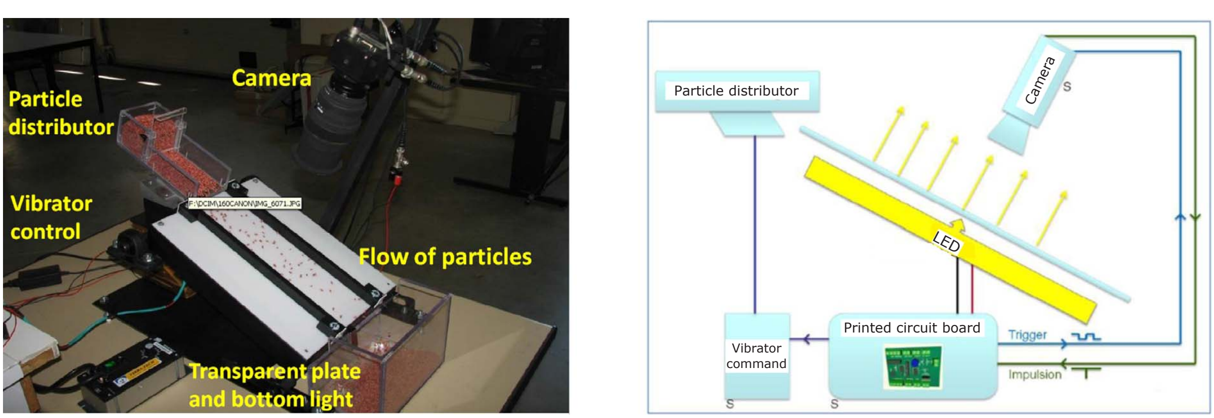


Fig. 3. Results of the calibration of image resolution. Image resolution is in px/mm. Presented shape parameters are CIRC, EL, IRR and RECT (see definition in Table A.2).

presented. Cool et al. (2016) analyzed fertilizer morphology by using X-ray micro-computed tomography. The sphericity parameter, defined by Chien (1994), was calculated and used to simulate the distance traveled by fertilizer particles through the drag equation defined in the same publication. However, this drag law was not proposed to determine the distance traveled in similar conditions to those encountered in the real-world spreading process (in true spreading conditions, fertilizer particles leave the end of the vane with an initial velocity between 140 and 220 km/h). The correlation between drag coefficient and morphology of fertilizers has not been sufficiently clearly established to explain the distance traveled by granules in real conditions.

The general purpose of this work was to discover whether any correlations exist between the morphology, modeled through shape parameters, and distance traveled by fertilizers spread out from real spinning discs. Goals included in this general purpose were to: (1) establish an image-based characterization of the morphology of fertilizers by developing a machine-vision system; (2) conduct experimental tests



(a) Imaging equipment (b) Working principle of machine vision system

Fig. 2. Machine vision system developed at Irstea Montoldre.