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Centrifugal Disc Spreading Quality as a Function of Feeding Position: Simulations and Experiments

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Abstract. A combination of an improved analytical model for the description of particle motion on the spinning disc and hodographic ballistics in the air was described earlier. The unified model (Gindert-Kele, 2006) is considered nearly exact for single particles leaving a conical disc with pitched straight vanes. "In-silico" spreading calculations with experimentally characterized particle clusters are sensitive to both spreader and fertilizer properties. However, parameters like loading area and air-drag coefficients may need empirical corrections. In this work experimental and simulated spreading patterns are compared demonstrating the importance of the angle selection for fertilizer feeding.

Keywords: fertilizer, spinning disc, spreading, quality

INTRODUCTION

Spinning disc centrifugal fertilizer spreaders are important since 90% of the 140 million tons/annum worldwide fertilizer production is spread using this simple and robust tool. Modelling of spreading is useful because of the possible substitution of expensive indoor experiments. A spreader with two spinning discs is implemented in the present calculations.

MATERIALS AND METHODS

The research has been carried out at the Department of Engineering, Centre for Agricultural Sciences University of Debrecen. In our earlier experimental studies (Gindert-Kele, 2003) we measured the individual air resistance factors k_{air} (Hofstee 1992, Grift 1997**)** and masses **m** for 250 particles. Fertilizer NPK 15-15-15 (Agrolinz Agrochemikalien GMBH) was used, particle friction factor on the vane $\boldsymbol{\mu}$ = 0.22, vane length $\mathbf{l_{vane}}$ = 0.40 m, internal radius of the disc $\mathbf{r_p}$ = 0.05 m (where the vanes are attached). The cone angle of the disc was $\boldsymbol{\Omega}$ = 9^o, the disc rotation frequency **n** = 840 rev/min, the tractor velocity $\mathbf{v_{tr}}$ = 8 km/h. The distance between the two discs is 0.9 m, and the disc vertical position is 0.9 m. The correction factor of experimental air drag coefficients was **cor** = 0.6. Constant angular window of 50^o of the loading orifice was used. Having these values fixed, we systematically changed the loading position on the disc (both experimentally and in the simulations), that was characterized by the centre angle of the loading orifice with respect to the x axis (perpendicular to tractor movement) and the radial centre of the feeding place. In the experiments the loading radius was in the 0.1 - 0.14 m range, while the central angle was changed between -39^o- 65^o. The experimental values were identical with those used as input for simulations. For thirteen different loading areas we have experimental and calculated results, that are compared and analyzed. Experimental spreading patterns were obtained from outdoor spreading tests using the weights of the collected bins that were further extrapolated with calculations to derive the spread patterns. All calculations were carried out with the MATLAB program package.

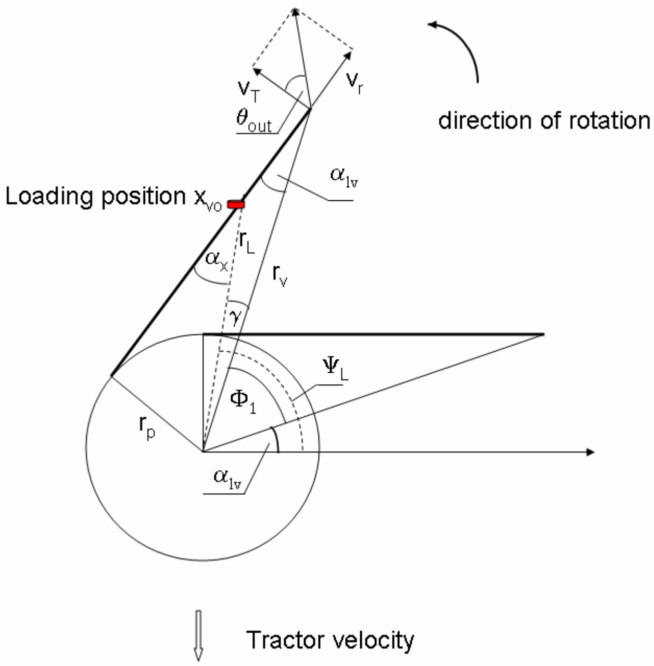

Fig. 1 Scheme of spinning disc that shows two rotated positions of the disc.

RESULTS AND DISCUSSIONS

Below we show the results of calculated spreading patterns with a "virtual spreader" that has closely related parameters to our test spreader. Calculations of particle sliding on the vane are extremely fast, since analytical formulas are used (Dintwa 2004). The calculated discharge velocity distribution is shown for the leaving particles. On the same figures the load angles and the mean of discharging directions is also shown. These are the inputs for the ballistic calculations (Kármán 1967) that yield the landing positions for each particle on the soil. For simplicity, the landing positions for the second disc are obtained as mirror images of the first disc.

Repeated calculations with incremented swath widthes give the most important characteristics of a spreader: the spreading quality (CV %) as a function of swath width. These calculations were accomplished in two ways. The traditional reference for the calculation of CV is equal with the pertinent swath width. Since in this case the reference bandwidth is reduced simultaneously with swath width, the quality of spreading will not be "spoiled" at small swath width. Traditional calculation also supposes a number of tractor turns on large arable lands. In our alternative approach only three tractor turns are considered in a "race track" sequence that predicts less uniform spreading at small swath width. The method presented here uses a *constant* reference bandwidth calculated from the difference of maximal and minimal casting distance. This kind of CV definition may be preferred to site specific applications, where only a finite number of tractor turns are necessary. Analyzing the results according to the new CV definition the number of useful swath widths can be predicted (those, that produce CV < 15%). For better comparison, the traditional way of CV determination is also applied and shown. The overall quality of the spreading can be calculated as a ratio of the area bordered by the pertinent CV curve and the limiting 15% CV line and referenced to the possible biggest 100% area (all zero CV) of the ‘experiments’. Fig. 2. shows a slightly skewed discharge velocity distribution, that can be compensated by the impact of the second disc.

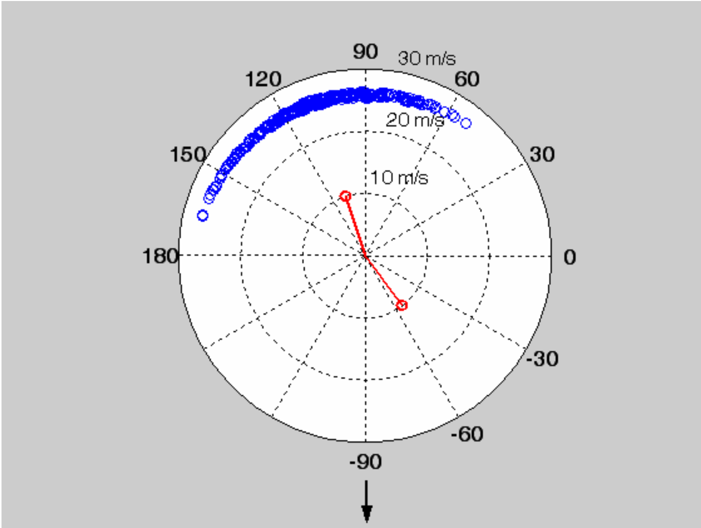

Fig. 2. Distribution of the velocities of discharging particles (feeding at -53° and 0.12m radius)

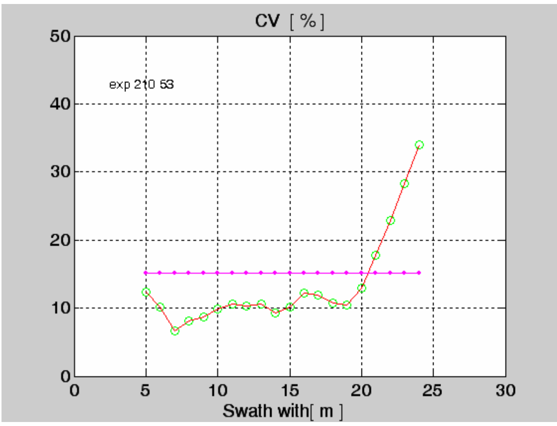

Fig. 3. Calculated CV% variances as a function of swath with (feeding at -53° and 0.12m radius)

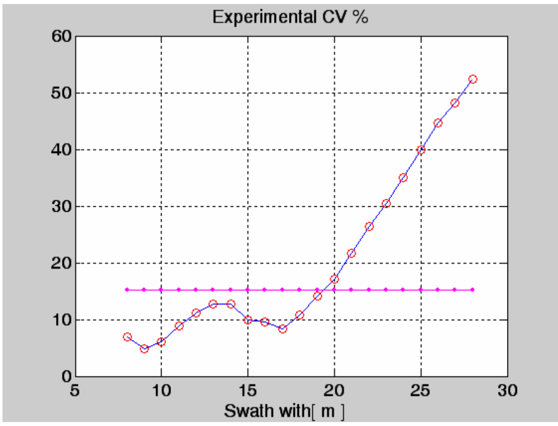

Fig. 4. Experimental CV% variances as a function of swath with (feeding at -53° and 0.12m radius)

Studying Fig. 3 and Fig. 4 we can compare the experiments and simulations for the given setting of the feeding orifice (-53^o). The agreement looks satisfactory, though we have to remember that the air drag cofficients are empirically corrected in the calculations. For completeness, Fig. 5 shows the experimental transversal spread pattern that is the input for the generation of the previous Fig. 4. Fig. 6 with a slightly miss set feed angle (-48^o) demonstrates that CV curves are rather sensitive to these parameters.

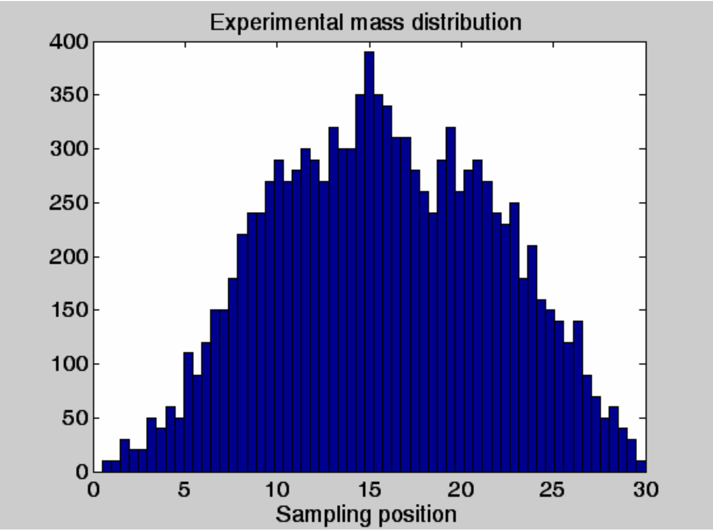

Fig. 5. Experimental transversal spreading pattern from the masses collected from the bins (feeding at -53^o and 0.12m radius).

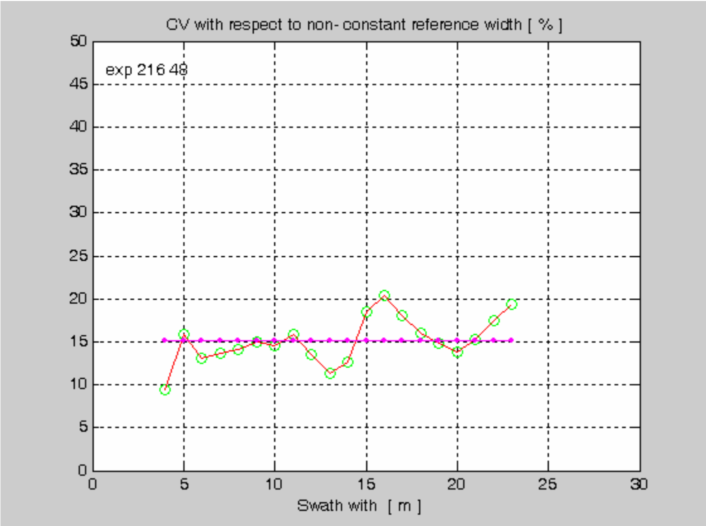

Fig. 6. Calculated CV% variances as a function of swath with (feeding at -48^o and 0.12m radius). This setting of the feeding orifice spoils the quality of spreading.

The results of all thirteen calculations are shown in Fig. 7, and it can be concluded, that the most uniform and robust spreading is expected in the - 65^o - 55^o feeding angle range. At values lower than -50^o, the spreading patterns become much worse, due to the parent transversal patterns, that exhibit two maxima.

Analyzing thirteen “virtual” experiments with the parameters of the real ones, the dependence of quality and robustness is shown as a function of the feed angle (Fig. 7). It can be seen that these properties abruptly decrease below -50°. Consequently, spreading wit such settings is not recommended.

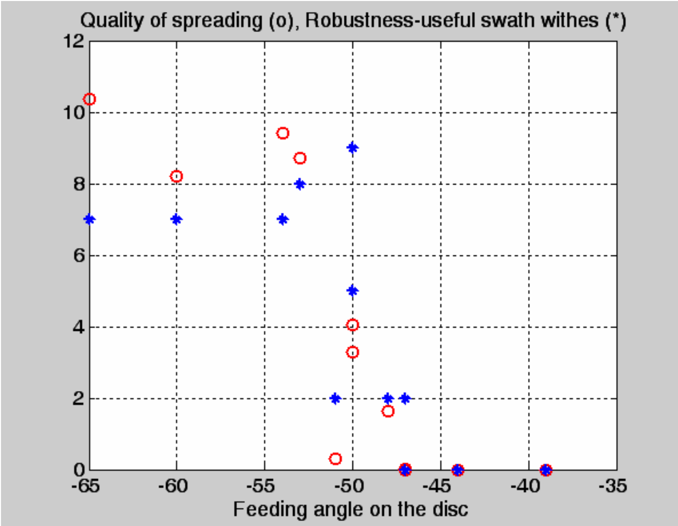

Fig. 7. Analysis of thirteen simulations shows that the quality and robustness of spreading breaks down at feed angles below -50°.

CONCLUSIONS

It has been shown experimentally and by calculations that the quality and robustness of spreading of centrifugal spreaders is very sensitive to the setting of the loading orifice angle. Therefore a careful adjustment may be critical in everyday practice.

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