A UNIFIED MODEL OF SPINNING DISC CENTRIFUGAL SPREADER

Gindert-Kele Ágnes *

* University of Debrecen, Centre of Agriculture, Department of Agricultural Engineering, 4028 Debrecen, Böszörményi str. 138. HUNGARY, e-mail: battane@agr.unideb.hu

Abstract

Spinning disc centrifugal fertilizer spreader is important since 90% of the 140 million tons/annum worldwide fertilizer production is spread using this simple and robust tool. Modelling is also important because of possible substitution of expensive indoor experiments. A combination of a recent analytical model for description of motion on a spinning disc and the hodographic ballistics is achieved. The combined model can be considered nearly exact for single particles leaving a conical disc with pitched straight vanes. The ballistic flight is approached with constant drag coefficient that is validated by the hodographic method. "In-silico" spreading experiments using experimentally characterized particle clusters are sensitive to spreader and fertilizer properties. Parameters like loading area on the disc and drag coefficient in the air however, may need empirical corrections to reliably simulate transversal spreading patterns and the quality of spreading as a function of working with. The present software tool may be put to good use in machine construction and teaching. A spreader with two spinning discs is implemented in the calculations. Two minutes CPU times of a laptop are sufficient for calculations with clusters of 250 particles.

Key words: model, spinning disc, centrifugal fertilizer spreader

MATERIALS AND METHODS

We have shown earlier (Gindert-Kele, 2003) that particle motion in the air (ballistics) can conveniently be simulated by Kármán's hodograph method. Now, I summarise the theoretical basis of single particle motion on the disc.

We applied the analytical model of S. Vilette, (2005) that was proven to yield identical results with known special cases (Patterson–Reece, 1962.) and superior with respect to earlier models of Olieslagers (1996) and Dintwa (2004) Their analytical model is able to mimic single particle movement on a spinning concave disc equipped with backward pitched vanes. We recall here only their basic results based on laboratory frame calculations. Additionally, we extend their model to two discs with explicit loading area, transform the discharge angle, consider discharge coordinates and tractor velocity. Using the same abbreviations as Vilette, we express constants K and δ as follows:

$$K = \frac{\mu g \cos\Omega + g \sin\Omega - \mu r \dot{\theta}^2}{\dot{\theta}^2 \cos\Omega(\cos\Omega - \mu \sin\Omega)}$$

$$\delta = \sqrt{\cos^2 \Omega(\mu^2 + 1) - \mu \sin \Omega \cos \Omega}$$

It is assumed that the vane meets a particle where it falls onto the disc (at r_l radial distance from the center and ψ angle with respect to the x-axis) and starts with zero velocity. The exact position and velocity of this particle along the vane as a function of time t can be obtained as :

$$x_v = \frac{(x_{v0} - K)}{2\delta} \times \left((\delta - \mu \cos \Omega) e^{-(\delta + \mu \cos \Omega)\dot{\theta} t} + (\delta + \mu \cos \Omega) e^{(\delta - \mu \cos \Omega)\dot{\theta} t} \right) + K$$

$$\dot{x}_v = \frac{(x_{v0} - K)}{2\delta} (\delta + \mu \cos \Omega)(\delta - \mu \cos \Omega) \dot{\theta} \times (e^{(\delta - \mu \cos \Omega)\dot{\theta} t} - e^{-(\delta + \mu \cos \Omega)\dot{\theta} t})$$

When this position equals to the vane length, the particle discharges from the vane. In practical calculations 60 ms time course of trajectory is monitored with 0.1 ms resolution, and the discharge time is determined numerically. Substituting the discharge time into previous we get the “exact” discharge velocity along the vane. This is an improvement over the original method. Then, the absolute value of the velocity is calculated, according to next eqution:

$$v = (\dot{x}_v \cos \Omega \cos \alpha_x) u_R + (r \dot{\theta} - \dot{x}_v \cos \Omega \sin \alpha_x) u_T + (\dot{x}_v \sin \Omega) k$$

The calculation of the ratio of the radial and tangential velocities requires an approach that was shown to cause less than 1% velocity errors along the vane for commercial broadcasters.

$$r_{RT} = \frac{v_R}{v_T} = \frac{(l_{vane} - K)(\delta - \mu \cos \Omega) l_{vane} \cos^2 \Omega}{r_{vane}^2 - (l_{vane} - K)(\delta - \mu \cos \Omega) r_p \cos \Omega}$$

The outlet angle is immediately obtained from this ratio as:

$$\square_{out} = \text{arc tan}(v_r/v_t)$$

If we express the outlet angle in the laboratory frame with respect to te x-axis perpendicular to the tractor movement (y-axis), then we get:

$$\theta_{out\_x} = \pi/2 - \theta_{out} + \psi - \alpha_x$$

where, using the r_p pitch radius of the internal circle of the disc,

$$\square_x = \arcsin(r_p/r_l)$$

Then the x and y components of the velocities of the discharging particles in the horisontal plane (The v_{tr} tractor velocity is subtracted in y direction):

$$v_x = v\cos(\Omega)\cos(\theta_{out\_x})$$

$$v_y = v\cos(\Omega)\sin(\theta_{out\_x}) - v_{tr}$$

So the absolute value of the leaving particle in the horisontal plane:

$$v_{hor} = [(v_x)^2 + (v_y)^2]^{1/2}$$

The angle of discharge with respect to the x-axis perpendicular to the tractor movement

$$\theta_{out\_x\_tr} = \arccos(v_x / v_{hor})$$

So we obtaine all necessary input parameters for ballistic calculations. For the ballistic calculations we assume that the drag coefficient C_D is nearly constant along the ballistic path of fertilizer particles.

RESULTS AND DISCUSSION

In earlier experimental studies we measured the individual drag coefficients and masses for 250 elements clusters of different fertilizers. Below we show the calculated results with a virtual fertilizer that posesses the following parameters:

Particle friction factor on the vane = 0.22, vane length = 0.40 m, cone angle of the disc = 9^o, tractor velocity = 8 km/h, disc rotation speed = 840 rev/min, distance between two discs 0.9 m, disc vertical position = 0.9 m, internal pitch radius of the disc = 0.05 m (where vanes are attached).

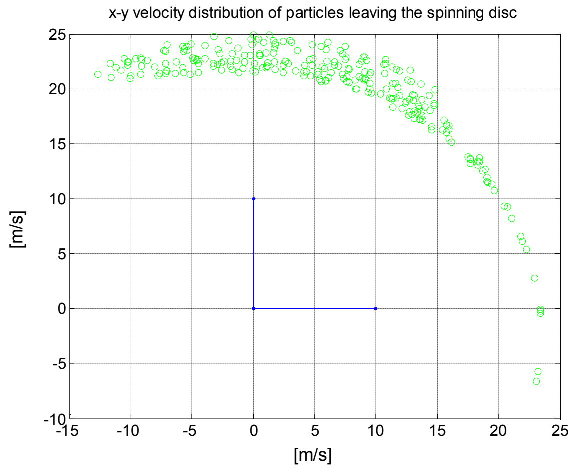

Figure 1. Velocity distribution of discharging particles calculated for one spinning disc on experimentally measured NPK15-15-15 fertilizer particles

Using these values constant we changed the loading area on the disc, characterized by the direction of the segment shaped orifice with respect to x direction (perpendicular to tractor movement) and the angular window of the segment. We found that if both angles are around 55^o, than the spreading is precise and robust. Using this loading area region *Fig. 1*. shows the calculated velocity distribution in x-y plane.

When the spinning disc calculations are ready, the discharge velocity vectors are known for each particles. These are inputs for ballistic calculations that yield the landing positions for each particle on the soil. For two spinning discs the symmetric landing positions on the soil are shown (*Fig.2.)*

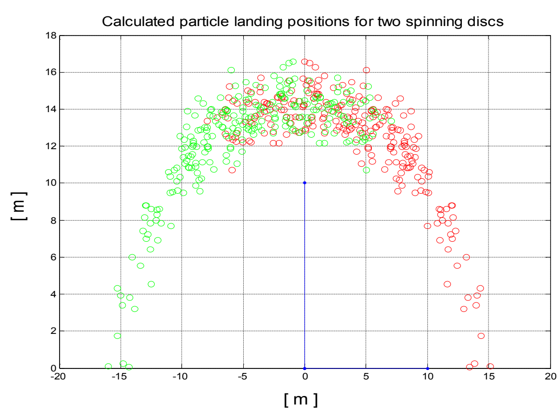

Figure 2. Theoretical landing position of NPK particles on the soil for a two-disc spreader

Using suitable geometric transformations the transversal spreading pattern (projection, *Fig. 3*) is calculated from the landing positions, furthermore the spreading quality can be deduced numerically. The predicted (rather uniform) transversal spreading pattern can be seen according to a 20 m working (swath) width of the tractor. The step-by step increment of working with characterizes the quality and robustness of spreading with the usual variability CV% parameter (*Fig. 4*). The quality is acceptable below 15 % level. These combined theoretical and experimental results are interesting, because outdoor experiments with small plot spreaders (Hagymássy, 2003/a, Hagymássy, 2003/b, Hagymássy, 2004/a) verified that evennes of spreading (Hagymássy, 2004/b, Hagymássy, 2005, Hagymássy, 2006) is particularly important.

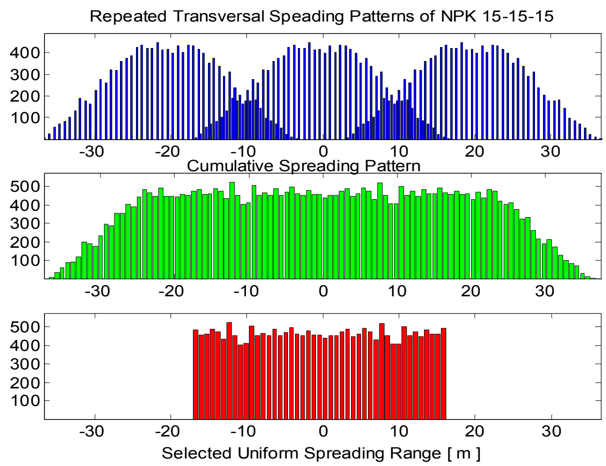

Figure 3. Transversal spreading pattern calculated from three tractor turns

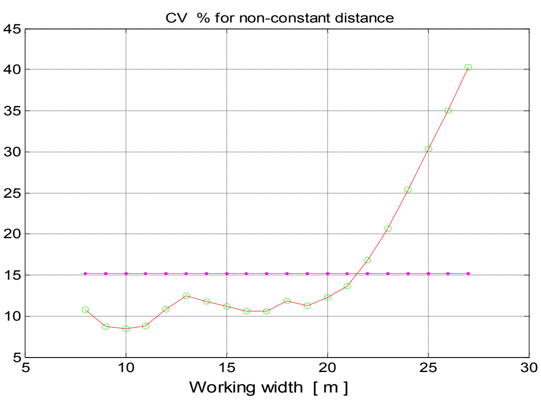

Figure 4. Quality (CV %) of spreading as a function of working width

CONCLUSION

As a conclusion of the present work we found that with our experimental conditions the most uniform spreading (lowest CV %) is expected around 50-55^o loading angle direction in a 55^o window. The robustness of spreading (insensitivity to changes of working width) is also best around the same value. On the other hand, the biggest working width can be achieved using a wider range of loading area up to 90^o. However, this way of improving the spreading capacity is risky, since unstable working width reduces the robustness and thereby the quality of spreading.

REFERENCES

1. Á. Gindert-Kele, 2003, *Predicting fertilizer spreading pattern*, Natural Resources and sustainable development, Oradea.
2. Dintwa, E., Van Liedekerke, P., Olieslagers, R., Tijskens, E., Ramon, H., 2004, *Model for simulation of particle flow on a centrifugal fertiliser sreader*. Biosystems Engineering 87 (4), 407-415. p.
3. Hagymássy Z., 2003.a, *A szántóföldi kisparcellás kísérletek gépesítése.* EU konform mezőgazdaság és élelmiszerbiztonság Tudományos Konferencia. Gödöllő. 142-148.
4. Hagymássy Z., 2003.b, Parcella műtrágyaszóró gép fejlesztése és munkaminőségének vizsgálata, Agrártudományi Közlemények, Debrecen.
5. Hagymássy Z., 2004.a, Kísérleti területek egyenletes tápanyag kijuttatásának műszaki feltételei, Doktori (PhD) értekezés tézisei, Debrecen.
6. Hagymássy, Z., 2006, *Parcella műtrágyaszóró gép átalakítása*, Debreceni Műszaki Közlemények 2006/1. 45-55.
7. Z. Hagymássy, 2004.b, *Approximate Model for Examination of Cone Dispenser Eccentricity*, Journal of Agricultural Sciences. 15. 47-49.
8. Z. Hagymssy, 2005, *Work quality examination of a plot fertilizer distributor.* Sustainable Agriculture Across Borders in Europe. Debrecen-Oradea. 165-169.
9. Oliaslagers, R., Ramon, H., Debaerdemaeker, J., 1996, *Calculation of fertilizer distribution patterns from a spinning disc spreader by means of a simulation model*. Journal of Agricultural Engineering Research 63, 137-152. p.
10. Patterson, D. E., Reece, A. R., 1962, *The theory of the centrifugal distributior I: Motion on the disc, near-centre feed*. Journal of Agricultural Engineering Research 7, 232-240. p.
11. Vilette, S., Cointault, F., Piron, E., Chopinet, B., 2005 *Centrifugal sreading: an analytical model for the motion of fertiliser particles on a spinning disc.* Biosystems Engineering 92 (2), 157-164. p.