CENTRIFUGAL FERTILIZER SPREADERS: WORKING SPEED VARIABILITY AND QUALITY OF WORK

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INTRODUCTION

The centrifugal fertilizer spreaders are widely used to provide nutrients for the different crops. Their quality of work, that is the **uniformity of distribution**, is directly related to the crop yield as well as the environmental protection. The most important technical parameters that influence the uniformity of spreading are:

1. **irregularity in the distribution pattern of the spreader**
2. **incorrect forward work-line along the field (i.e. pattern overlapping)**
3. **variations in the spreader work speed**

1. Applying a **specific** fertilizer by means of a **specific** spreader, **a specific** unitary distribution pattern is given. Shape and uniformity of this pattern depend on the setting made by the farmer on the machine, according to the manufacturer's recommendations. Overlapping contiguous passes on the field a multiple profile is obtained and the Coefficient of Variation CV_p expresses **the overall uniformity of the lateral distribution**.

Relation	Parameters
$CV_p = \frac{\sigma_q}{\bar{q}} \cdot 100$	σ_q [*kg/min*] flow rate std. dev. over the spreading width $\bar{q}$ [*kg/min*] flow rate mean value over the spreading width

2. To minimize CV_p a **useful working width** b_u, [*m*] has to be selected, and this identifies an **optimal (straight) work-line**. Because of the difficulty to maintain this line during all the spreading operations, it is assumed that the probability for the machine to be located - at any time - at a **distance b from the optimal work-line follows a normal distribution**.

Relations	Parameters
$f(b) = \frac{1}{\sqrt{2\pi} \cdot \sigma_b} \cdot e^{-\frac{b^2}{2\sigma_b^2}}$ $CV_{ol} = \frac{\sigma_b}{b_u} \cdot 100$	σ_b [*m*] distance from optimal line std. dev. b_u [*m*] useful working width

3. Many factors cause variations in the spreader forward speed (soil slope, shape and size of the plot, wheels slip, reversing the travel-direction, farmer driving ability etc.). Again, the **spreader forward speed is assumed to follow a normal distribution**.

Relations	Parameters
$f(v) = \frac{1}{\sqrt{2\pi} \cdot \sigma_v} \cdot e^{-\frac{(v-\bar{v})^2}{2\sigma_v^2}}$ $CV_v = \frac{\sigma_v}{\bar{v}} \cdot 100$	σ_v [*km/h*] spreader speed std. dev. $\bar{v}$ [*km/h*] spreader speed mean value

TOTAL DISTRIBUTION ERROR AND APPLIED FERTILIZER RATE FREQUENCY FUNCTION

During the spreading operation, the above causes of error can co-exist. Each of them contributes - with different weight - to obtain a non-uniform fertilizer distribution. The real application rate over the plot is determined by **adding** the:

- variability effects **along** the travel direction (work speed variations) and
- **lateral** variability effects (work-line deviations), connected to the non-uniformity distribution pattern and its incorrect overlapping.

By simulating - step by step - the spreader movement on the field, it is possible to evaluate the applied fertilizer rate D_k, [*kg/ha*] on elementary areas A_k (width Δx and length Δy, [*m*]) in which distribution pattern and work speed can be assumed uniform. The rate D_k over each area A_k, is obtained adding the m_k [*kg*] fertilizer masses distributed on A_k during each field-passes interesting that elementary area.

$$D_k = \frac{\sum_{j=1}^{n_d} m_{k,j}}{\Delta x \cdot \Delta y} = \frac{1}{\Delta x} \cdot \sum_{j=1}^{n_d} \frac{q_{k,j}}{v_{k,j}}$$

The simulation **output** is:

1. Applied Fertilizer Rate Frequency Function *f* (D_i)
on all the elementary areas which form the plot

2. Total Coefficient of Variation $CVT = \frac{\sigma_D}{\bar{D}} \cdot 100$

EXPERIMENTAL TESTS

While for the distribution patterns data are available (manufacturers' technical information, official standard tests etc.), both for the forward speed variations and the deviation from optimal work-line during the fertilizing operation, experimental data must be collected taking into account different spreading conditions (soil slope, field shape and dimensions, operator skill, tractor and machine age, tractor instrument equipment etc.).
Consequently, for each type of operating situation, it will be possible to apply the most appropriate CV values and to calculate the fertilizer rate distributed on the field. Furthermore, knowing the crop yield response to the fertilizer rate, the function $f(D_i)$ can

be used for a more rigorous calculation both of the economic benefit deriving from the crop, as well as, the machinery pay-back period.

Experimental tests are still in progress; this paper reports two typical work conditions in Po-valley (Italy) farms (**Table 1**).

These tests concerned the spring fertilizing operations, ordinary executed in Italy before the maize and soybean seeding; the used fertilizers were the NPK (10-25-25) and the urea (46% of N), distributed at different rates and by the spreaders set at different work widths (**Table 2**).

Table 1 – Po-valley (Italy) farms A and B: parameters classification and work conditions

	Soil Slope	Field Shape	Ave. plot area [*ha*] and dimen.	Operator Skill	Spreader Age [*year*] And type	Tractor age [*year*] and type	Control Instrum. Equipped
	0 flat **+ medium** **++ high**		**1-5** **5-10** **10-15** **> 15**	**+++ very high** **++ high** **+ good** **0 sufficient**	**1-2** **2-5** **5-10** **> 15**	**1-2** **2-5** **5-10** **> 15**	
A	0	Regular	10-15 600*m*·200*m*	+++	2-5 2 discs	2-5 4 WD	Yes
B	0	Regular	1-5 200*m*·150*m*	0	5-10 1 disc	15-20 2 WD	No

Table 2 – Fertilizers, application rates and spreader work widths

	Farm A	**Farm B**
Fertilizer	Urea	Urea
Nomin. applic. rate [*kg/ha*]	400	200
Work width [*m*]	27	12

For the in-filed speed measurements, a magnetic sensor cabled with a portable data-logger, directly located inside the tractor cab, was used. It senses the signal of eight magnets mounted on the internal part of the rear wheel of the tractor, sending to the data-logger an impulse sequence proportional to forward speed. Data-logger was switched-on at the beginning of the spreading and switched-off at the end. The speed variation analysis permits to reconstruct all the fertilizing operation phases (**Figures 1 and 2**).

The deviation of the spreader from the optimal work-line, was evaluated measuring, for each pass of the machine on the plot, the distance between two contiguous tractor-wheel traces on the soil; the measures were repeated every 100 *m* along the pass.

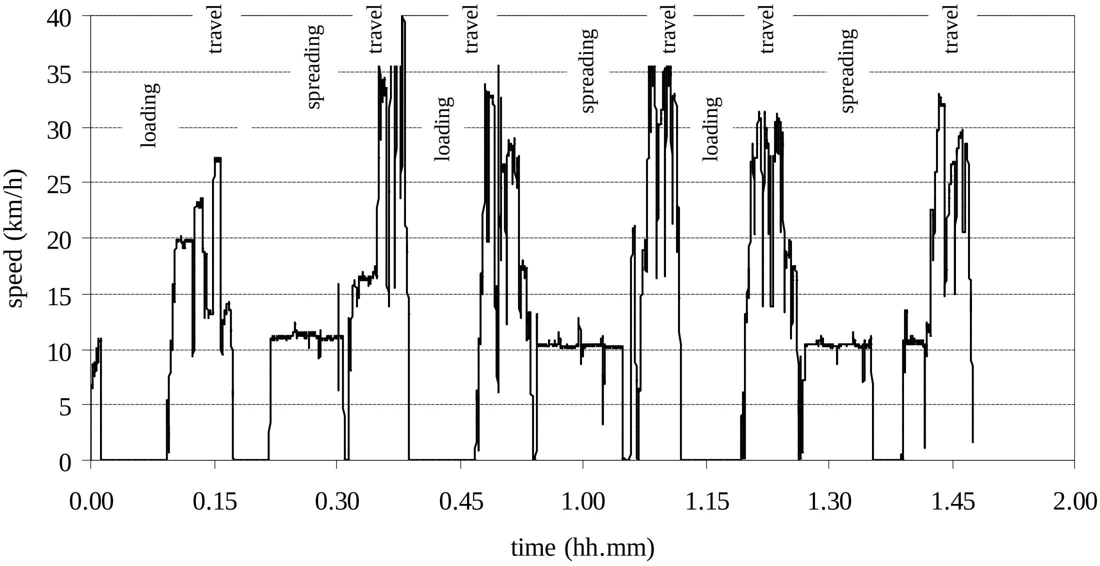

Figure 1 - Farm A: an example of tractor speed curve during the fertilizing operation over a plot

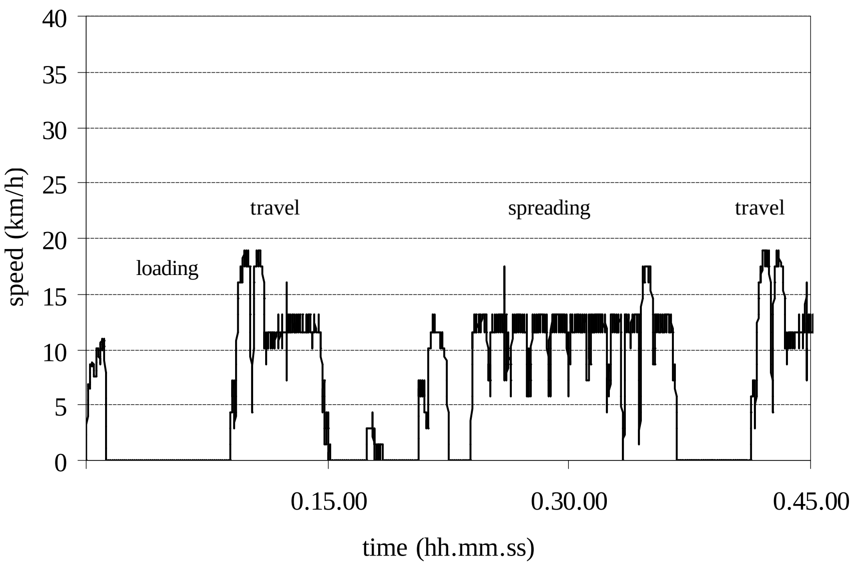

Figure 2 - Farm B: an example of tractor speed curve during the fertilizing operation over a plot

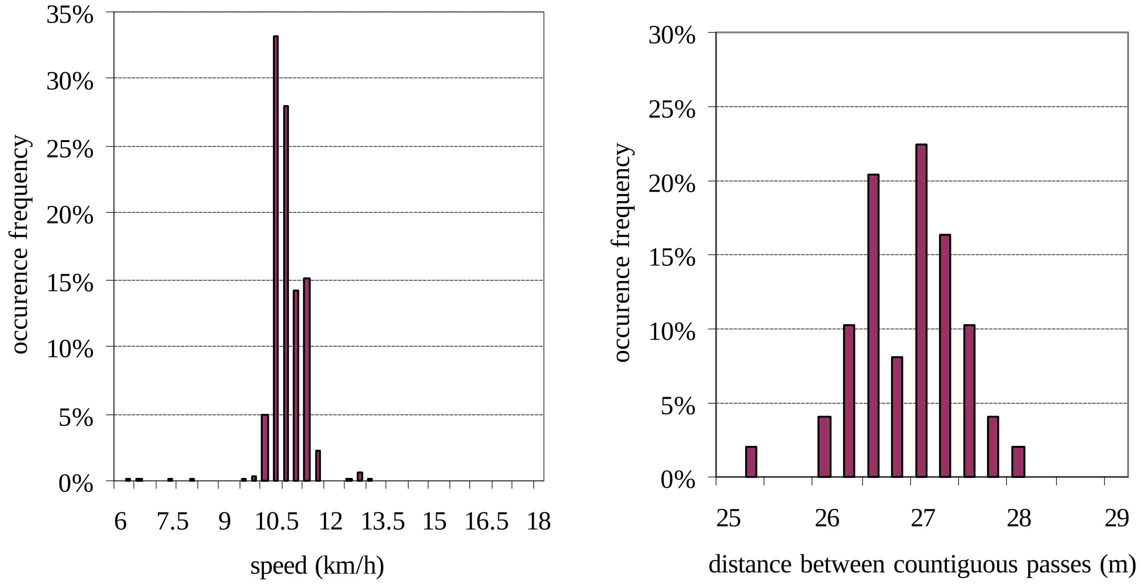

Figure 3 - Farm A: occurence frequency of forward speeds and of distance between contiguous passes maintained during spreading reported in Fig.1

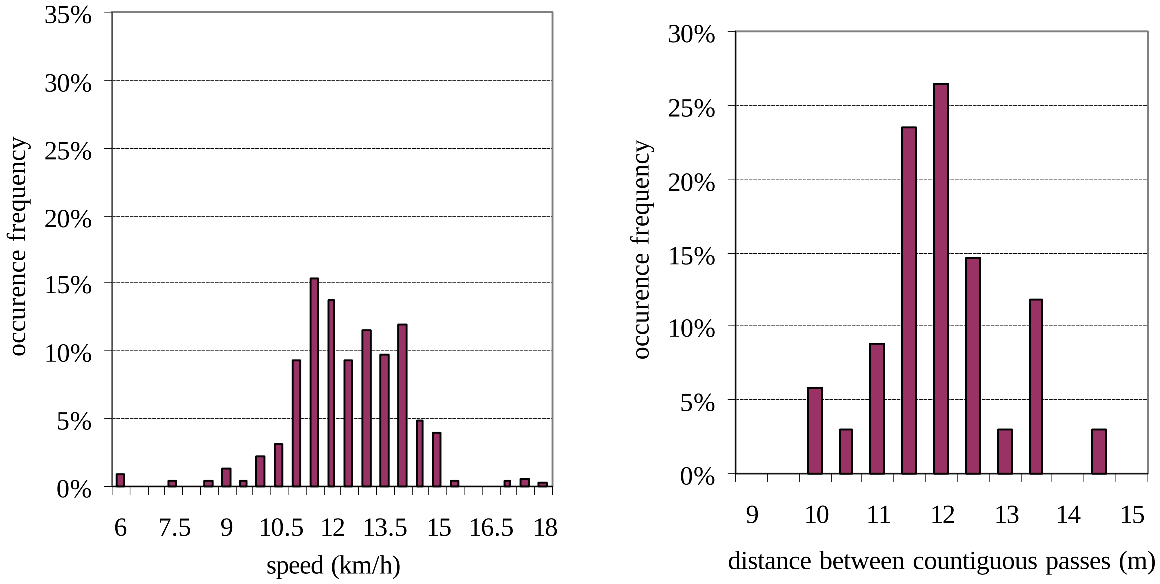

Figure 4 - Farm B: occurence frequency of forward speeds and of distance between contiguous passes maintained during spreading reported in Fig.2

Summarizing all the experimental data, the following Coefficients of Variation resulted:

- under "good" working conditions of the Farm A: CV_v = 5.6 % and CV_{ol} = 2.0%;
- under "poor" working conditions of the Farm B, CV_v = 13.8% and CV_{ol} =9.2%.

MODEL APPLICATION AND RESULTS

A simulation was conducted assuming the experimentally determined parameters, concerning the unitary distribution pattern, considering the condition of the spreader machine, a Coefficient of Variation CV_p = 5% and 17% for Farm A and B was, respectively, assumed. **Table 3** summarizes the running parameters and the input data.

Results obtained for two typical cases show a Total Coefficient of Variation CVT=10.8% under the good operating conditions of farm A, and CVT=31.4% under the poor operating conditions of farm B.

Table 3 – Model application: parameters and input data

Farm	A	B
Plot dimensions	Width b_{LA} = 200 *m* Length b_{LU} = 600 *m*	Width b_{LA} = 150 *m* Length b_{LU} = 200 *m*
Elementary areas n° and dimensions	n_A = 120000 Δx = 0.5 *m*; Δy = 2 *m*	N_A = 30000 Δx = 0.5 *m*; Δy = 2 *m*
Spreader working width	b_u = 27 *m*	Working width b_u = 12 *m*
Fertilizer and nominal applic. rate	Urea D_0 = 400 *kg/ha*	Urea D_0 = 200 *kg/ha*
Pattern: CV_p	5%	17%
Speed: CV_v	5.6% (σ_v = 0.6 *km/h*)	13.0% (σ_v = 1.6 *km/h*)
Overlap: CV_{ol}	2.0% (σ_b = 0.55 *m*)	9.2% (σ_b = 1.10 *m*)

On the basis of each site-specific numerical information, by simulating the spreader movement on the field, the model calculates the uniformity of fertilizer distribution, identifying the applied rate occurence frequency function and the Total Coefficient of Variation CVT (**Figures 5 and 6**).

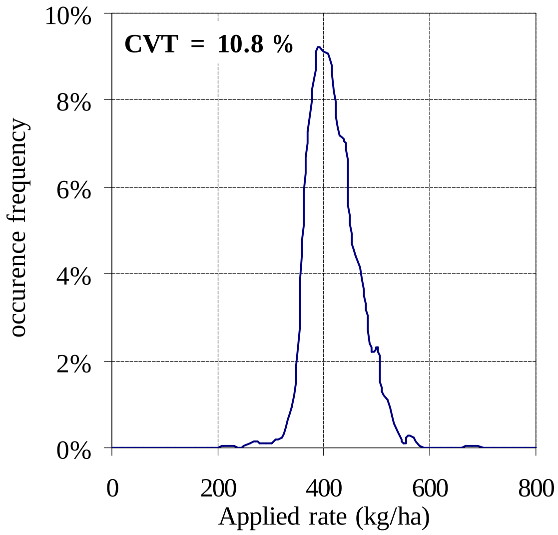

Figure 5 – Farm A: Applied Rate Frequency Function and CVT

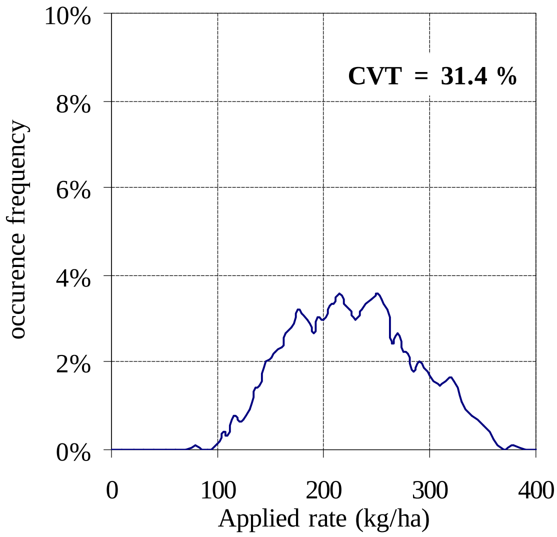

Figure 6 – Farm B: Applied Rate Frequency Function and CVT

CONCLUSIONS

A simulation model was developed to determine the non-uniformity of distribution of a centrifugal fertilizer spreader operating on a generic plot. The non-uniformity was expressed as an applied rate occurrence frequency function $f(D_i)$ and as a Total Coefficient of Variation (CVT) which provides a total index of work quality.

The model takes into consideration errors in applied fertilizer rate caused by: **a)** irregularities in the distribution pattern; **b)** incorrect forward work-line along the plot; **c)** variations in the work speed.

Results obtained for two typical cases show a Total Coefficient of Variation of 10.8% under the good operating conditions of farm A, and of 31.4% under the poor operating conditions of farm B corresponding to using old or unadjusted machines and low working accuracy.