CIGR

International Commission of
Agricultural Engineering

Proceedings

13th INTERNATIONAL CONGRESS
ON
AGRICULTURAL ENGINEERING

Rabat (Morocco)
2-6 February 1998

VOLUME 3

AGRICULTURAL MECHANIZATION

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Proceedings / Actes

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AGRICULTURAL MECHANIZATION

MECANISATION AGRICOLE

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Published by ANAFID 2, Rue Haroun Errachid, Rabat – Morocco

For the complete set of six volumes ISBN 9981-1887-0-0
For volume 1: ISBN 9981-1887-1-9
For volume 2: ISBN 9981-1887-2-7
For volume 3: ISBN 9981-1887-3-5
For volume 4: ISBN 9981-1887-4-3
For volume 5: ISBN 9981-1887-5-1
For volume 6: ISBN 9981-1887-6-X

Printed in Morocco / Imprimé au Maroc
Dépôt légal : 90/1998

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Work Quality of a Fertilizer Spreader Equipped with a DPAE Control System

Marco Fiala and Roberto Oberti [*]

ABSTRACT

The field performance of a spreader depends on both transversal and longitudinal uniformity of the fertilizers distribution. On the basis of the experimental tests on a DPAE control system (distribution proportional to work speed), carried out with 3 different fertilizers, at 3 application rates and at 8 speeds (6 to 13 *km/h*), a model to calculate the total Coefficient of Variation of the spreader was defined, determining a global index of its work quality. Moreover, knowing the fertilizer responses to the different arable crops and quantifying the total distribution error, it has been obtained a preliminary evaluation of the economic benefit related to the use of a spreader equipped by a DPAE system.

Keywords: fertilization, rate control, distribution uniformity

INTRODUCTION

Within the more advanced agricultural systems, Precision Farming (PF) is the topic on which much of the current scientific research in Agricultural Engineering has been focused (Stafford ed., 1997). This is due to the development of technologies able of localising machines in the field, controlling their operations and processing information, thereby enabling site-specific control of field operations.

However, the widespread adoption of PF is subordinated to several technical and economic factors; this points out the insufficient maturity of PF and hinders its rapid commercial diffusion.

There are also particular situations - such as those existing in Italian agriculture - whose structural characteristics (fragmentation of plots, shape and layout of fields, disformity of crops, farm organisation, etc.) constitute further causes against the adoption of this new system of "agricultural management" (Mazzetto et al., 1997).

Consequently, it is still a general interest to analyse the performance of farm equipments used in the traditional agriculture, for which the smallest unit of reference is the whole plot. In this connection, one of the most interesting aspects is the evaluation of the work quality improvements which can be obtained through the adoption of innovations (sensors, control systems, etc.), not necessarily integrated into a PF system.

This paper analyses the main causes of errors in the application rate of fertilizers, and the impact of such errors on the economic performance of a particular crop. However, this approach disregards the systematical and/or instrumental errors connected to the measurement of the variables.

FERTILIZER CROP RESPONSE, FERTILIZER RATE AND CROP PROFITABILITY

For certain types of crops (cereals, roots and tubers), several studies (Kling, 1986; England, 1986; Shiles, 1989; Morrison et al., 1980; Sequi ed., 1997) correlate - for nitrogen only - the crop yield Y (*t/ha*) with the fertilizer rate D (*kg/ha*) (**Fig. 1**).

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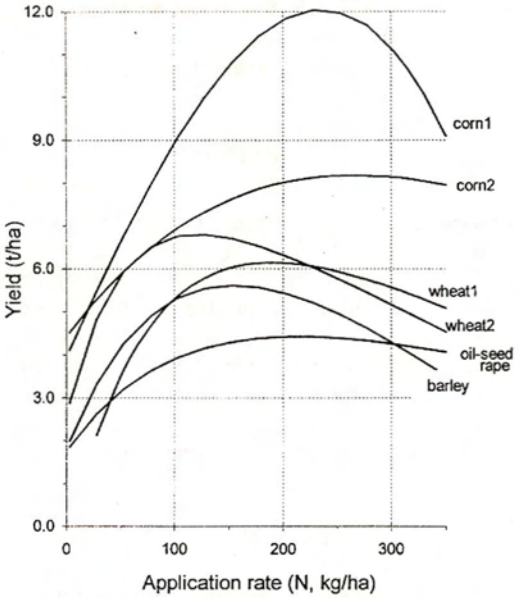

Fig. 1 - Yield response vs. nitrogen fertilization

The various Y(D) functions, notwithstanding common characteristics (concavity towards the bottom, a single maximum Y_M at a rate D_M, a value $Y(0) > 0$), exhibit marked numerical variability even within the same crop; this clearly limits the applicability of these functions to the site and conditions of the experimental measurements.

Nevertheless it is possible to make a few general considerations. In fact, isolating the contribution of fertilizer rate from the other production factors, the profit per unit of surface (specific profit P_s; *ECU/ha*) obtainable for a specific crop is given by:

$$P_s(D) = Y(D) \cdot p_u - D \cdot c_u \qquad [ECU/ha] \qquad (1)$$

where p_u (*ECU/t*) is the sale price of the product and c_u (*ECU/t*) is the cost of each unit of fertilizer.

The optimal fertilizer rate D_o (*kg/ha*) must verify the condition $\frac{dP_s}{dD} = 0$; differentiating (Eq.1) the optimal fertilizer rate is obtained when:

$$Y'(D) = \frac{c_u}{p_u} \qquad (2)$$

D_o is therefore the fertilizer rate for which the derivative of the yield response function is equal to the ratio between fertilizer cost and product price (**Fig. 2**).

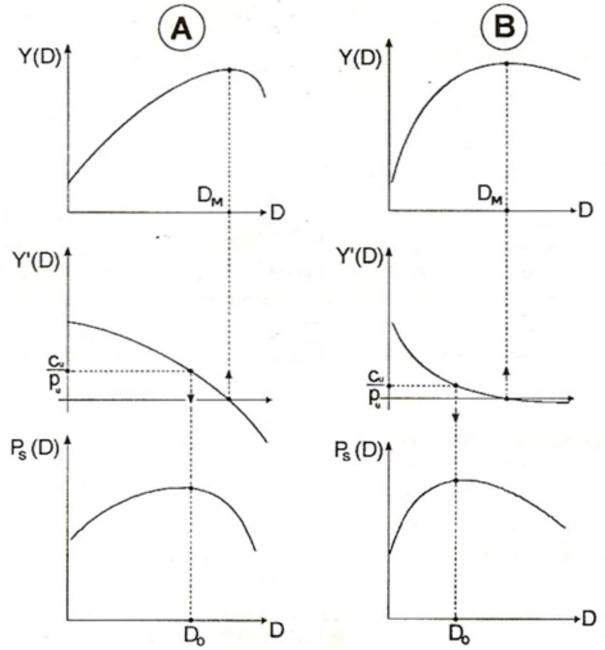

Fig. 2 - Qualitative yield response functions to nitrogen fertilization for cereals (A) and roots/tubers (B); identification of the optimal fertilizer rate D_0 and the maximum yield fertilizer rate D_M; effect of the applied fertilizer rate on the specific profit P_s obtainable from the crops.

CAUSES OF ERROR IN THE FERTILIZER RATE

Assuming that the fertilization requirements of a plot are homogeneous - i.e. that the fertilizer application rate D_t *(kg/ha)* must be the same over the whole plot area A *(ha)* - by operating with a centrifugal spreader with application/distribution components properly functioning (constant fertilizer flow rate Q, *kg/min*; constant spinner rotation speed ω, *rmp*), the possible causes which can lead to an error in the fertilizer application rate D_t are:

i. irregular spreader pattern;
ii. incorrect forward travel-line (trajectory) along the field;
iii. variations in the work speed.

For evaluating the cost/benefit ratio of a technological innovation aiming to minimise such errors is essential to quantify their effect on the economic performance of the crop.

NON-UNIFORM FERTILIZER DISTRIBUTION AND CROP PROFITABILITY

Subdividing the plot surface A *(ha)* into elementary areas - whose dimensions (Δx; Δy) are chosen so that two adjoining areas exhibit a non-uniform fertilizer distribution - the specific profit of the plot A - defined by (Eq.1) - can be expressed as the mean of the individual specific profits of each elementary area:

$$P_s(D) = \overline{P_s}(D) = \overline{Y(D) \cdot p_u - D \cdot c_u} = \overline{Y}(D) \cdot p_u - \overline{D} \cdot c_u \qquad [ECU/ha] \qquad (4)$$

In (Eq.4), the distribution of the fertilizer rate arount its mean value $\overline{D}$ has no effect on the term $\left(\overline{D}\cdot c_u\right)$, although - being $\overline{Y}(D) \neq \overline{Y}(\overline{D})$ - it does influence the term $\left(\overline{Y}(D)\cdot p_u\right)$.

If $f(D_i)$ is the statistical distribution of the fertilizer rates in the individual elementary areas, (Eq.4) becomes:

$$P_s(D) = \overline{Y}(D)\cdot p_u - \overline{D}\cdot c_u = p_u \cdot \sum_{i=1}^{n_{cl}} f(D_i)\cdot Y(D_i) - \overline{D}\cdot c_u \qquad [ECU/ha] \qquad (5)$$

where: n_{cl} is the number of classes into which the fertilizer rate range is subdivided.

Equation 5 expresses the concept, observed also in practice, that the specific crop profit P_s is influenced by the yield and, therefore, by the uniformity with which the operator distributes the chosen fertilizer rate.

It is therefore necessary to analyse the behaviour of $f(D_i)$ in relation to the causes of error previously identified.

Irregular Fertilizer Spreader Pattern

The application of a specific fertilizer with a specific spreader has an associated "unitary distribution pattern".

The shape and uniformity of this pattern depend on the adjustments (ground height, speed of rotation, fin length and angle, etc.) made by the operator on the spinners in accordance with the Manufacturer's recommendations.

The pattern is determined experimentally by means of standardised tests (ASAE S341.2; ISO 5690/1) conducted at various testing centers (CEMAGREF, NLH, Statens Maskin-Provningar etc.).

The overall uniformity of the lateral distribution - obtained from the partial overlap of several adjoining passes ("multiple profile") - is expressed by a Coefficient of Variation, given by:

$$CV_p = \frac{\sigma_q}{\overline{q}}\cdot 100 \qquad (6)$$

where: σ_q *(kg/min)* is the standard deviation of the fertilizer flow rate of the collected samples and $\overline{q}$ *(kg/min)* is the mean of these values.

The reference values commonly used for CV_p (Balsari et al., 1994; Yule et al., 1996) are shown in **Table 1**.

Table 1 - Lateral distribution Coefficient of Variation

UNIFORMITY of LATERAL DISTRIBUTION	COEFFICIENT of VARIATION (%)
Excellent	$0 \le CV_p \le 5$
Good	$5 < CV_p \le 10$
Fair	$10 < CV_p \le 15$
Inadequate	$15 < CV_p \le 20$
Poor	$CV_p > 20$

For the purposes of this study, the unitary distribution pattern - determined by the operator's adjustments and regulations - is assumed to be constant for all the passes which make up the complete field fertilization operation.

Incorrect Forward Travel-line (Trajectory) Along the Plot

There exists a useful distance b_u (*m*) between adjoining passes which overlaps two unitary distribution patterns in such a way as to minimise the Coefficient of Variation CV_p. This distance b_u is determined on the basis of the distribution pattern, usually through iterative numerical calculations (Balsari et al., 1994; NLH, 1996).

In this way an optimal travel-line, usually rectilinear, is determined; the spreader must follow it in order to obtain all the operation passes equidistantly spaced by b_u.

In practice, however, the operator is unlikely to maintain the optimal travel-line for the entire fertilization operation; therefore, this study assumes that the actual field position of the fertilizer spreader exhibits a normal distribution around the optimal distance b_u.

The probability that the spreader is located, at any given time, at a distance b (*m*) from the optimal trajectory is given by:

$$f(b) = \frac{1}{\sqrt{2\pi} \cdot \sigma_b} \cdot e^{-\frac{b^2}{2\sigma_b^2}} \tag{7}$$

The travel-line error b has a negative effect on the uniformity of distribution, generating a non-optimal multiple distribution profile.

The magnitude of the variance (σ_b^2) depends on the possibility of identifying and maintaining the optimal travel-line in the plot (driving ability, field conditions, etc.).

Variations in the Work Speed of the Fertilizer Spreader

Many factors can cause variations in the work speed of a spreader, such as: soil slope and irregularities, shape and size of the plot, slip of the tractor driving wheels, reversing the direction of travel and the associated manoeuvres, ability of the operator.

Because the experimental data available only quantify work speed variations for similar operations (Grisso et al., 1988), we assume that the speed of the spreader follows a normal distribution:

$$f(v) = \frac{1}{\sqrt{2\pi} \cdot \sigma_v} \cdot e^{-\frac{(v-\bar{v})^2}{2\sigma_v^2}} \tag{8}$$

The value of the variance (σ_v^2) depends, obviously, on the magnitude of the causes described above under the various operating conditions.

Total Distribution Error

During a fertilizer-spreading operation, the causes of error separately analysed above can coexist, contributing in varying proportion to the non-uniform distribution of the fertilizer.

The actual distribution over the entire plot is in fact determined by summing up the longitudinal variability effects (*y* axis, travel direction) - caused by variations in the work speed of the machine - and the lateral variability effects (axis *x*), caused by irregularities in the spreader pattern and its incorrect overlap due to travel-line deviations.

The plot A can be subdivided into A_k elementary areas of width Δx (*m*) and length Δy (*m*). Inside each $A_k = \Delta x \cdot \Delta y$, values for both the distribution pattern and the work speed are assumed to be uniform.

In practice, the transverse dimension Δx coincides with the resolution used to subdivide the unitary distribution pattern ($\Delta x = 0.5 - 1.0$ *m*), whereas the dimension along the travel direction Δy, which takes into account the speeds variations, falls in the range $\Delta y = 1.0 - 2.0$ *m*.

In the case of a rectangular field, the total number of elementary areas n_A will be:

$$n_A = \left(\frac{b_{LA}}{\Delta x}\right) \cdot \left(\frac{b_{LU}}{\Delta y}\right) \tag{9}$$

where b_{LA} (*m*) and b_{LU} (*m*) are, respectively, the total plot width and length.

By simulating the movement of a fertilizer spreader on the field, it is possible to evaluate the fertilizer rate D_k (*kg/ha*) distributed on each elementary area A_k.

To this end, along a single pass, for each forward step Δy of the unitary distribution pattern:

1. the forward speed varies, using random values calculated by (Eq.8).
2. the spreader pattern laterally shifts from the optimal travel-line, using random values calculated by (Eq.7).

The procedure is repeated for each pass of the fertilizer spreader, until the whole plot width b_{LA} (*m*) has been covered.

DETERMINING THE FUNCTION f(D$_i$)

The fertilizer rates D_k (*kg/ha*) in each of the elementary areas A_k (*ha*) are given by:

$$D_k = \frac{\sum_{j=1}^{n_d} m_{k,j}}{\Delta x \cdot \Delta y} = \frac{1}{\Delta x} \cdot \sum_{j=1}^{n_d} \frac{q_{k,j}}{v_{k,j}} \qquad [kg/ha] \tag{10}$$

where: n_d is the number of times (usually 1 or 2) that the unitary spreader pattern "passes over" that A_k; $v_{k,j}$ (*km/h*), $m_{k,j}$ (*kg*) and $q_{k,j}$ (*kg/min*) are, respectively, the different work speeds, the masses and the fertilizer flow rates in the n_d distributions which pass over elementary area A_k.

Because the travel-line errors of the fertilizer spreader cause a lateral shift in the spreader pattern, it is necessary to redefine - for each trajectory variation - the fertilizer rates distributed on the underlying elementary areas. For this purpose, by plotting the unitary pattern as a broken-line diagram and averaging the values of the broken-line portion that fall upon A_k, it is possible to determine the flow rate $q_{k,j}$ (**Fig. 3**).

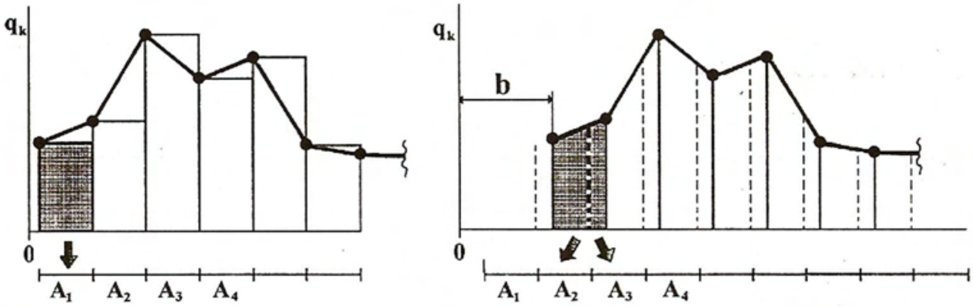

Fig. 3 - Effect of unitary profile shift (b) on the amount of fertilizer distributed on the various elementary areas A_1,...., A_4,....

The used algorithm can be summed up in the following steps:

```
1. for each pass from 1 to $\left(\frac{b_{LA}}{b_u}\right)$;
    2. for each forward step from 1 to $\left(\frac{b_{LU}}{\Delta y}\right)$;
        3. calculate v (km/h) work speed (Eq.9);
        4. calculate b (m) deviation from optimal travel-line (Eq.8);
        5. translate the unit pattern into $x = (pass \cdot b_u + b)$;
        6. calculate $q_k$ (kg/min) fertilizer flow rate for each elementary area $A_k$ which falls under the unit spreader pattern;
        7. calculate $D_k$ (kg/ha) fertilizer rate for each $A_k$ of point 6) (Eq.10);
        8. add $D_k$ to the fertilizer rates previously distributed on $A_k$;
    9. next forward step;
10. next pass.
```

This algorithm, implemented using a common programming language, permits the simulation of various operating conditions. These are defined through parameters related to the spreader (unitary spreader pattern, work speed, nominal fertilizer rate) and to work conditions (speed variations given by σ_v; travel-line deviations given by σ_b).

The output of the program is the frequency of the fertilizer rate distributed on the n_A elementary areas into which the plot was subdivided. This defines the function $f(D_i)$, necessary for calculating the profit in (Eq.5).

APPLICATION OF THE CALCULATION MODEL

Centrifugal Fertilizer Spreader Equipped with an Electronic Controller for Distribution Proportional to Work Speed (DPAE)

Adopting a DPAE controller on a centrifugal spreader should eliminate non-uniformity in the fertilizer distribution, because the variations in the work speed of the machine are balanced by a proportional variation in the flow rate of fertilizer to the spinners.

This is equivalent to consider the effect of speed variations on distribution equals to zero, i.e. to set $\sigma_v = 0$ in (Eq.9).

However, experimental tests conducted on a fertilizer spreader equipped with a DPAE (Fiala et al., 1997) have shown that the DPAE does not totally eliminate the fertilizer rate errors due to variations in the work speed. The data collected during these tests indicate a Coefficient of Variation set in the range $2.5\% \le CV_v \le 6.0\%$.

For the application of the simulation model it is possible to assume, for this type of machine, an average work speed $\bar{v} = 10$ *km/h* and a $CV_v = 4.0\%$ ($\sigma_v = 0.4$ *km/h*).

For the other causes of error, two different operating conditions are simulated (**Table 2**):

- Case A: excellent lateral distribution quality ($CV_p = 5.0\%$); excellent spreader travel-line ($\sigma_b = 0.5$ *m*; $CV_{ol} = \frac{\sigma_b}{b_u} = 2.1\%$);
- Case B: poor lateral distribution quality ($CV_p = 17.0\%$); large deviations of the spreader from the optimal travel-line ($\sigma_b = 1.5$ *m*; $CV_{ol} = 6.3\%$).

A plot of width $b_{LA} = 250$ *m* and length $b_{LU} = 250$ *m*, subdivided into $n_A = 62500$ elementary areas (each measuring $\Delta x = 0.5$ *m* by $\Delta y = 2$ *m*), fertilized with nitrogen at the nominal application rate $D_t = 220$ *kg/ha* by a centrifugal spreader with a working width of $b_u = 24$ *m* is considered.

Table 2 - Application of the model to a spreader equipped with a DPAE in two different operating conditions: Coefficients of Variation

OPERATING CONDITIONS	CV_v	CV_p	CV_{ol}
Optimal (Case A)	4.0% (σ_v = 0.4 *km/h*)	5.0%	2.1% (σ_b = 0.5 *m*)
Poor (Case B)	4.0% (σ_v = 0.4 *km/h*)	17.0%	6.3% (σ_b = 1.5 *m*)

The results of the simulations are reported in **Figures 4** and **5**; they show how uniformity of distribution is affected by incorrect adjustment of the spreader spinners and by deviations from the optimal travel-line. The broader the curve obtained for $f(D_i)$, the stronger the negative correlation.

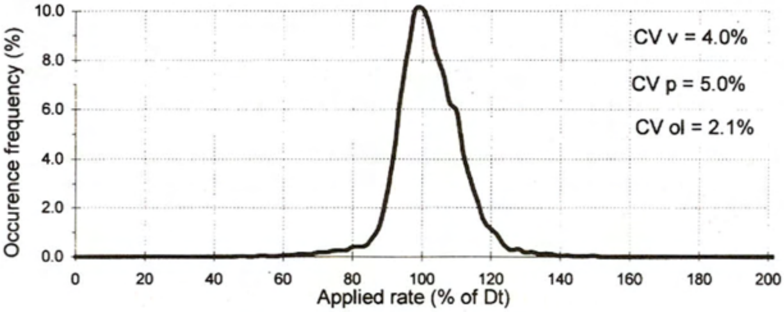

Fig. 4 - Applied rate occurrence frequency: Case A

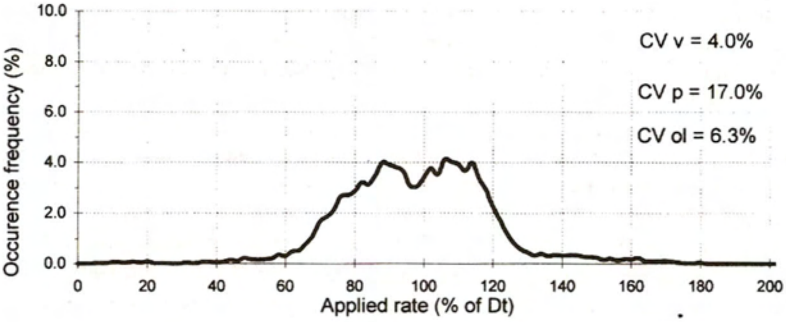

Fig. 5 - Applied rate occurrence frequency: Case B

The Coefficient of Variation of the applied rate can provide an index of the total work quality of a centrifugal spreader:

$$CVT = \frac{\sigma_D}{\overline{D}} \cdot 100 \tag{11}$$

Moreover, the $f(D_i)$ obtained from the simulation permits to calculate by (Eq.5) the specific benefit obtainable from a particular crop.

As an example, a field cultivated with corn, whose yield response to nitrogen fertilization Y(D) (*t/ha*) lies midway between (see **Fig. 1**):

$$Y_1(D) = 4.42 + 3.32 \cdot 10^{-2} \cdot D - 8.84 \cdot 10^{-5} \cdot D^2 + 6.60 \cdot 10^{-8} \cdot D^3$$

$$Y_2(D) = 3.94 + 5.56 \cdot 10^{-2} \cdot D - 3.91 \cdot 10^{-5} \cdot D^2 - 2.22 \cdot 10^{-7} \cdot D^3$$

is considered.

Assuming a corn sale price p_u = 105 *ECU/t* (excluding tax), a specific cost of nitrogen c_u = 450 *ECU/t* (excluding tax) and using into (Eq.5) the $f(D_i)$ resulting from the Cases A and B simulations, the specific benefits detailed in **Table 3** were obtained.

Table 3 - Application of the model to a spreader equipped with a DPAE in two different operating conditions: technical and economic results

OPERATING CONDITIONS	CVT (%)	ECONOMIC PARAMETERS *(ECU/t)*	YIELD RESPONSE FUNCTION *(t/ha)*	ECONOMIC BENEFIT *(ECU/ha)*
Optimal (Case A)	**9.6**	p_u = 105	$Y_1(D) = 4.42 + 3.32 \cdot 10^{-2} \cdot D - + 8.84 \cdot 10^{-5} \cdot D^2 + 6.60 \cdot 10^{-8} \cdot D^3$	**760÷1160**
Poor (Case B)	**21.6**	c_u = 450	$Y_2(D) = 3.94 + 5.56 \cdot 10^{-2} \cdot D - + 3.91 \cdot 10^{5} \cdot D^2 - 2.22 \cdot 10^{-7} \cdot D^3$	**740÷1120**

Conventional Centrifugal Fertilizer Spreader

For spreaders which are not equipped with a speed controller, it is necessary to evaluate the magnitude of CV_v.

In the lack of experimental data, an average work speed of $\bar{v}$ = 10 *km/h* and an operating situation for which the work speed falls in the range $7 \leq v \leq 13$ *km/h* in 95% of the cases (CV_v = 15.0%; σ_v = 1.5 *km/h*), were simulated.

In order to compare the results, for both other error causes (**Table 4**) and operating variables, the same hypotheses of Cases A and B were assumed.

Table 4 - Application of the model to a conventional spreader in two different operating conditions: Coefficients of Variation

OPERATING CONDITIONS	CV_v	CV_p	CV_{ol}
Optimal (Case C)	15.0% (σ_v = 1.5 *km/h*)	5.0%	2.1% (σ_b = 0.5 *m*)
Poor (Case D)	15.0% (σ_v = 1.5 *km/h*)	17.0%	6.3% (σ_b = 1.5 *m*)

The results obtained for Cases C and D are shown in **Figures 6** and **7.**

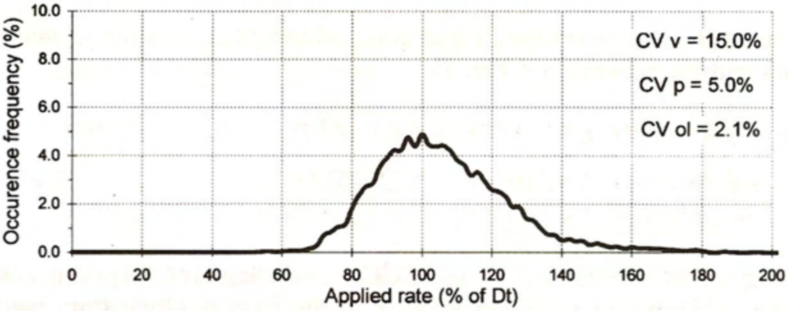

Fig. 6 - Applied rate occurrence frequency: Case C

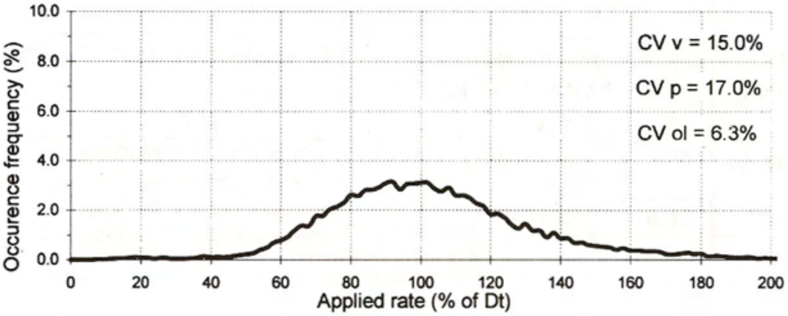

Fig. 7 - Applied rate occurrence frequency: Case D

Considering, for the Cases C and D, the same crop and the same economic parameters, the specific benefits obtained are shown in **Table 5**.

Table 5 - Application of the model to a conventional spreader in two different operating conditions: technical and economic results

OPERATING CONDITIONS	**CVT** (%)	ECONOMIC PARAMETERS *(ECU/t)*	YIELD RESPONSE FUNCTION *(kg/ha)*	ECONOMIC BENEFIT *(ECU/ha)*
Optimal (Case C)	**18.1**	$p_u = 105$ $c_u = 450$	$Y_1(D) = 4.42 + 3.32 \cdot 10^{-2} \cdot D +$ $- 8.84 \cdot 10^{-5} \cdot D^2 + 6.60 \cdot 10^{-8} \cdot D^3$	**745÷1120**
Poor (Case D)	**28.9**		$Y_2(D) = 3.94 + 5.56 \cdot 10^{-2} \cdot D +$ $- 3.91 \cdot 10^{5} \cdot D^2 - 2.22 \cdot 10^{-7} \cdot D^3$	**725÷1070**

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 an 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 travel-line along the plot; c) variations in the work speed.

The algorithm was used to simulate the behaviour of a centrifugal spreader equipped with DPAE controller under two different operating situations (Case A: optimal conditions; Case B: poor conditions), obtaining CVTs of 9.6% and 21.6%, respectively.

Comparison of these indices stresses out the high incidence on work quality of both the distribution pattern (spinners regulation) and the spreader travel-line (passes overlapping) and, consequently, the importance to put under constant control these work parameters.

For each simulated case and on the basis of two different yield response functions to nitrogen fertilization, the function $f(D_i)$ has been used to calculate the economic benefit related to a corn cultivation. Under the simulation assumptions, the Case B-conditions led, in comparison with the Case A-conditions, to a reduction of the economic benefit from 20 to 40 *ECU/ha*.

It is important to stress that, unknowing the function $f(D_i)$, that means to neglect the non-uniformity of fertilizer distribution, the economic benefit of the crop would be wrongly calculated on the basis of the average fertilizer rate (according to Eq.1).

The model was also applied to a conventional fertilizer spreader, assuming conditions (Case C and Case D) comparable to those used for simulating the DPAE spreader. The corresponding CVTs, 18.1% (Case C) and 28.9% (Case D), were significantly worse than the previous ones.

From the economic standpoint, comparing the results with those of the DPAE-equipped spreader, a further reduction (15÷50 *ECU/ha*) in the crop benefit was achieved.

The study highlights that the work quality of centrifugal spreaders can be substantially improved by adopting systems and/or devices capable of, on the one hand, controlling variations in work speed (DPA, DPAE) and, on the other hand, identifying the optimal travel-line with greater precision (row-tracing, drive control).

Finally, it should be emphasised that the experimental determination of the actual work speed during field operations would permit an even more rigorous calculation of the economic benefits, under various working conditions, connected with adoption of DPAE systems on fertilizer spreaders.

REFERENCES

Balsari P., Airoldi G., (1994). Spandiconcime (Fertilizer spreaders). Edagricole, pp. 82

England R.A., (1986). Reducing the nitrogen input on arable farms. Journal of Agricultural Economics, 37(1): 13-24

Fiala M., Oberti R., (1997). Prove di DPAE per il controllo della distribuzione su uno spandiconcime ad azione centrifuga. (Experimental tests of a DPAE control system installed on a centrifugal fertilizer spreader). Proceedings 6th National A.I.I.A. Congress, September 10-12, Ancona, Italy, Vol. 3, 557-565

Grisso R.D., Hewett E.J., Dickey E.C., Schnieder R.D., Nelson E.W., (1988). Calibration accuracy of pesticide application equipment. Applied Engineering in Agriculture, 4(4):310-315

Kling A., (1986). Possibilities and limits of nitrogen fertilization. Economic aspects demonstrated for different crops. Nitrogen, 14, Frankfurt/Main

Mazzetto F., Vaccaroni M., Lazzari M., (1997). Agricoltura di precisione: realtà e prospettive.(Precision farming: reality and prospects). Proceeding 6th National A.I.I.A. Congress, Ancona, Italy, September 10-12, Vol. 3, 271-280

Morrison J., Jackson M.V., Sparrow P.E., (1980). The response of perennial ryegrass to fertilizer nitrogen in relation to climate and soil. Grassland Research Institute, Hurley, Technical report n.27

NLH-Institutt for Tekniske Fag, (1996). Melding Prove (Nordsten Logic NN), N.3-1996, Norway

Sequi P. (ed.), (1997). Progetto finalizzato Produzione Agricola Nella Difesa dell'Ambiente (PANDA).(Project "Agricultural productivity protecting the environment"). Agricoltura e Ricerca, 167, 5-54; 168, 5-100

Shiles R., (1989). Nitrogen for winter barley. Agtec., 1988/89, Hydro Fertilizers Ltd., Ipswich, England

Stafford J. (ed.), (1997). Precision Agriculture '97. Proceedings 1st European Conference, Vol. I: Spatial Variability in Soil and Crop, Vol. II: Technology, 7-10 September 1997, Warwick University Conference Centre, UK, pp. 991

Yule I., Crooks E., 1996. Precision farming: the price of imperfection. Landwards, Spring, 5-9