Prediction of Pesticide Distribution on the Ground Based on Boom Sprayer Movements

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Abstract
The horizontal and vertical movements of boom sprayers are among the causes affecting the quality of distribution. Based on previous experiences, a simple and reliable system has been developed to record the movements of two points of a boom under field conditions. The steadiness and efficiency of the machine can be better defined using the movements data to directly estimate their effect on the distribution. This is possible through their elaboration and by considering the geometrical characteristics of the booms and of the nozzles adopted. To this purpose a data processing method has been realized and, after the validation tests in laboratory, its application has been extended to field conditions where the boom undergoes real shocks determined by soil unevenness: the effects of the movements on the quality of distribution have been quantified for each nozzle and expressed in diagram form. Aimed at more direct visualization, a color map of the sprayed area is shown in which the pattern of distribution values is expressed as variation of intensity of gray tones.

Keywords
Boom sprayer, movements, distribution

Introduction

Vertical and horizontal movements of boom sprayers represent one of the elements affecting the quality of pesticide distribution and the effectiveness of the treatments. These movements, determined by several factors such as the length of the boom, the type of suspension system, the soil unevenness and the correct tractor-sprayer coupling, are responsible for the variation of each nozzle position and velocity referred to the optimum ones. Vertical movements produce variations of the height of the nozzles, determining, as a consequence, areas over-sprayed by contiguous nozzles and areas under-sprayed or unsprayed: in any case the quantity of product distributed at ground differs from the optimum value.

In consequence of horizontal movements the velocity of the nozzles referred to the ground is not the same as the tractor, but it increases or decreases when the boom oscillates horizontally. This means that each nozzle can spray the same area for a time longer or shorter than the time determined by the velocity of the tractor. Vertical and horizontal movements combined with the geometrical characteristics of the boom (length, suspension, articulation joint, etc.) could heavily affect the quality of distribution. Different methods and instruments can be used to measure boom movements. One of them has been realized at ISMA (Pochi & Vannucci, 2001, 2002): it is capable of working on operating booms. The data processing provides the three spatial components of the movement and other information. In this work the data

processing system has been developed in order to give the prevision of the distribution depending on the boom geometrical characteristics and its movement pattern.
Such a system could be useful in a large scale investigation on the efficiency of both used and new boom sprayers.

Purpose

As said above, previous works (Pochi & Vannucci, 2001, 2002), proposed a system aimed at collecting and process the movement data of boom sprayer in field conditions producing information on boom steadiness. The system consists of the measuring instruments, the equipment for their application to the boom and the data processing methodology. It underwent tests under different conditions such as test track and field, showing good reliability and accuracy and to be easy to use.
In this work, the attention is paid to the data processing methodology that has been developed in order to further elaborate the movement data and calculate the distribution at ground under working conditions.
Experimental tests have been carried out with the system in laboratory on a single nozzle to validate the data processing methodology through the comparison between *expected (calculated)* and *observed* distribution.
Then, the system has been used in field tests in which the data of boom movement have been collected and used to calculate the position of each nozzle and, consequently, the resulting distribution at ground .

1. Materials and Method

1.1 – Laboratory tests

The system realized to monitor boom movements in field conditions consists of a series of three potentiometric transducers (Pochi & Vannucci, 2001), as follows (*fig. 1*):

- one wired linear transducer, giving the variation of the position of the point where it is applied through the measurement of the wire length variation. The maximum length of the wires is 1320 mm, with a 0.01% linearity. The electrical signal range is 0-5000 mV.
- two angular transducers (linearity: 0.05%) suitably connected with the wire transducer to give its angle variations during boom movements, so that it is possible to trigonometrically define the position of the inspected points through the *x, y* and *z* coordinates. According to this, the X axis identifies the horizontal movements (longitudinal) along the travel direction; the Y axis identifies the horizontal movements perpendicular to the travel direction (transversal movements); the Z axis identifies the vertical movements.
- A data acquisition system recording the electrical signals of the transducers to be processed and a PC complete the instrumentation.

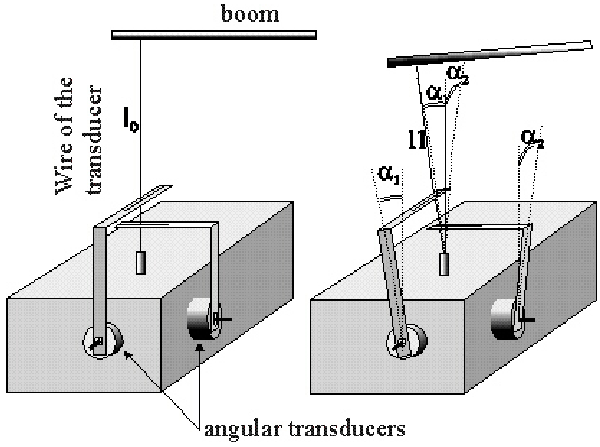

Fig. 1 - Scheme of the system based on potentiometric transducers

The system has been applied to a structure simulating a boom sprayer, supporting a single nozzle, as showed in *figure 2*. An important characteristic of the simulated boom was its capability to reassume its initial position after being excited. The boom excitation was impressed during the passage of a cart pulled by an electric motor along a rail and at a constant velocity. The cart supported a vertical bar; at the top of the bar a little wheel was suitably placed with the function of hitting the boom and producing a series of horizontal and vertical oscillations whose behavior does not show significant variations if the conditions of cart velocity and wheel diameter do not change. This repeatability is testified by the results of many repetitions reported in *table 1.* The effects of the cart velocity and wheel diameter are showed in *figure 2*.

Table 1
Analysis of the variance of the average, standard deviation and coefficient of variation of the movement data determined by different values of cart velocity and wheel diameter. Three repetitions have been carried out under each condition and the differences among them have never significance.

Analysis of the variance of the average

Factor of variability	*Horizontal movements*			*Vertical movements*		
	Variance	*F calc.*		*Variance*	*F calc.*	
total						
repetition	123,99	3,19		5,66	0,78	
obstacle	224,80	5,77	*	418,32	57,48	**
speed	1301,39	33,45	**	21,20	2,91	
comb. interaction	3,77	0,10		11,87	1,63	
Error	38,90			7,28		

Analysis of the variance of the standard deviation

Factor of variability	*Horizontal movements*			*Vertical movements*		
	Variance	*F calc.*		*Variance*	*F calc.*	
total						
repetition	0,15	0,08		0,52	2,67	
obstacle	90,23	50,30	**	65,73	335,76	**
speed	1058,34	589,94	**	45,53	232,57	**
comb. interaction	7,06	3,94		2,73	13,96	
Error	1,79			0,20		

Analysis of the variance of the Average

Factor of variability	*Horizontal movements*			*Vertical movements*		
	Variance	*F calc.*		*Variance*	*F calc.*	
total						
repetition	32,55	1,25		5,40	1,16	
obstacle	4534,61	174,64	**	2804,04	603,96	**
speed	689,69	26,56	**	547,59	117,94	**
comb. interaction	461,27	17,76		345,00	74,31	
Error	25,97			4,64		

* *Significant at 95%*
** *Significant at 99%*

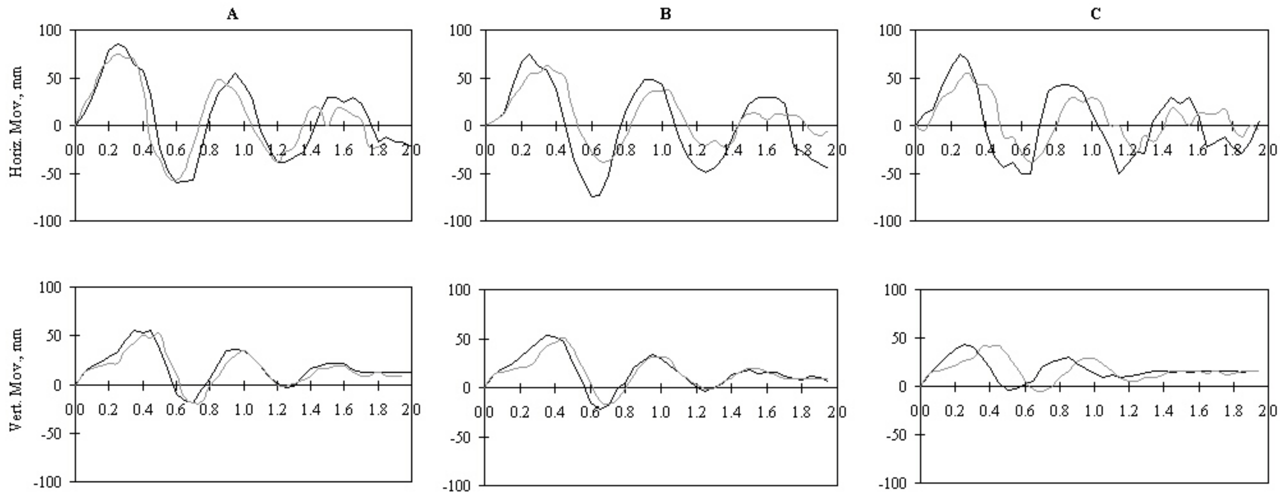

Fig 2 - Pattern of horizontal and vertical movements of the boom under different conditions in laboratory tests. Each curve has been drawn according to the series of data resulting from the average of three repetitions. A, 12.5 cm wheel diameter; B, 10 cm wheel diameter; C, 8 cm wheel diameter.
——— *cart velocity: 0.462 m/s*
——— *cart velocity: 0.306 m/s*

Knowing the movement data of the point where the transducers were applied, it is possible to calculate the horizontal and vertical movements and velocity of the nozzle. Considering its characteristics, such as its spraying angle, its flow rate and the initial height, it is possible to calculate the variations of the spraying width and the dose distributed at ground. The results of these calculations had to be validated.

Table 2
Conditions of the laboratory tests

Type of nozzle	-	flat fan
Nozzle flow rate	l/min	3.41
Nozzle height	mm	283
Nozzle spraying angle	°	65
Width of distribution	mm	340
Frequency of acquisition	Hz	20
Cart speed	m/s	0.33
Dose at 0,33 m/s speed	mm	0.525
Number of test tubes	n	240
Test tubes diameter	cm	2.7
Test tubes grid length	mm	580
Test tubes grid width	mm	600
Longitudinal rows of the grid	n	15
Transversal rows of the grid	n	16
Total number of test tubes	n	240

The conditions of the validation test are described in *tab.2* A very small velocity value and a high flow rate nozzle were adopted in order to increase, as much as possible, the quantity of water sprayed into the test tubes, making the reading of the results easier. The test tubes, supported by a frame on the cart, moved under the nozzle collecting the sprayed water. The test tubes disposition was to form a rectangular grid (*fig. 3*) providing the pattern of the actual distribution to which the calculated distribution had to be compared.

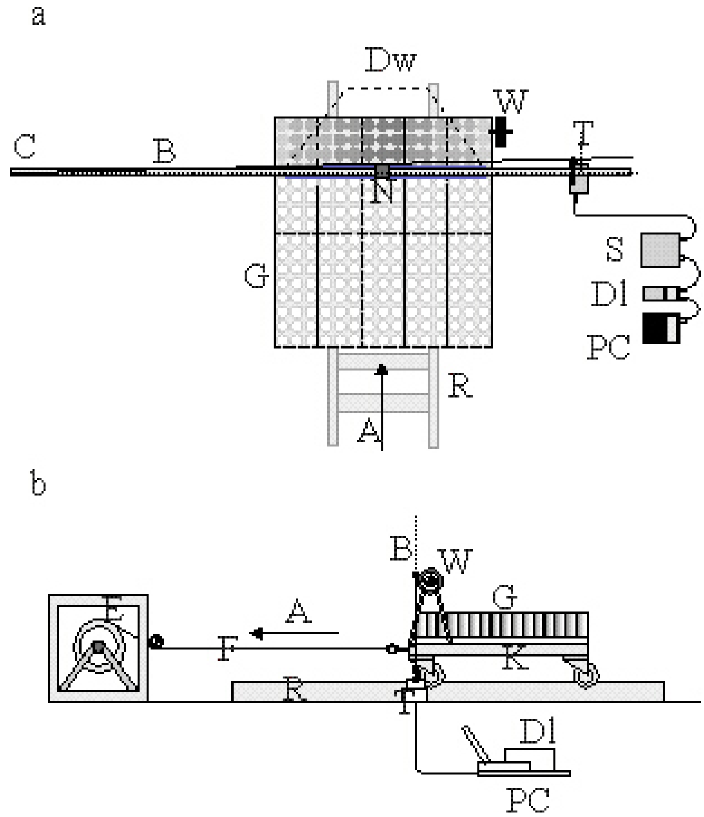

Fig. 3 - Laboratory tests: scheme of utilization of the instruments and equipment. a) top view showing the grid of cylindrical test tubes under the nozzle mounted on a bar simulating a boom sprayer; b) side view showing the cart pulled on the rail by an electric motor and the wheel determining the boom excitation.
A - travel direction; B - bar simulating a boom sprayer; C - center of the boom; D - data logger; E - electric motor pulling the cart (K) on the rail (R) by means of the wire F; G - test tubes grid positioned on the cart and collecting the water sprayed by the nozzle N; PC - personal computer; Sw - spraying width; Wh - wheel mounted on the cart and determining the boom excitation; T - group of transducers measuring the movements of the boom

Since the boom was in a fixed position, the cart velocity was assumed as the travel velocity. The nozzle velocity resulted, instant by instant, from the algebraic sum of the travel velocity (velocity of the cart) and the horizontal component of the velocity (positive or negative) determined by the movement impressed to the boom by the wheel. The tests were carried out in conditions of unexcited and excited boom. In both cases ten repetitions have been carried out, monitoring boom movements and collecting the water in the test tubes. The quantity of water in each test tube was measured using a precision

balance and expressed as volume (cm^3): dividing this value by 10 provides the average volume collected after one passage. Referring the water volume (cm^3) to the surface of the test tubes section (cm^2), the amount of product (dose) can be expressed as ***[cm³/cm²]*** or as ***[10 x cm³/cm² = mm].*** The latter unit has been adopted in this paper to indicate the doses of liquid.
The water contents of the test tubes grid give the pattern of the distribution both longitudinally (test tubes columns) and transversely (test tubes rows).
Considering the geometrical characteristics of the nozzle, the vertical movement data were processed to obtain the pattern of the variations of the height and calculate the relative variations of the spraying width. On the other hand, the horizontal movements have been used to determine the variations of the horizontal velocity of the nozzle referred to the ground..
Considering the interval between two consecutive acquisitions (t_a = 0,05 s), the distance covered in this time by the nozzle can be calculated from the nozzle velocity: the area sprayed in t_a results as the product of the distance in t_a and the mean spraying width (average of the two values at the beginning and at the end of each interval t_a.
Multiplying the nozzle flow rate(expressed as cm^3/s) by t_a (s) will give the volume (cm^3) sprayed in t_a . The ratio between this and the area sprayed in t_a (cm^2) will provide the dose sprayed (*cm*) by the nozzle in t_a. In the data processing, these doses are multiplied by 10 and expressed in *mm*.
The dose calculated for a nozzle as just described can be identified as the mean value of its transversal distribution in one point. The series of values determined in this way refers to t_a and give the pattern of the longitudinal distribution on the test tubes grid. It has been compared with the series of 16 values referred to the 16 transversal rows. Each of these values results as the average of the 15 test tubes contents of each row. Nevertheless, the actual pattern of the transversal distribution observed in the test tubes in the laboratory test, is not constant, showing a maximum centrally, under the nozzle and decreasing as the distance from the center increases (see fig. 6-A): the procedure adopted to simulate this pattern in the elaboration is described in the annex A.

1.2 – Application of the system in field tests.
The transducers system described above has been applied to a 12 m suspended boom mounted on a tractor moving in a field. Two series of tests have been conducted: in the first series the suspension system was working (suspended boom); in the second it had been disconnected (unsuspended boom).
The above mentioned method used to calculate the nozzle movements and the pattern of the distribution has been extended to all the 12 flat fan nozzles of the right arm of the boom. The characteristics of the nozzles and the other test conditions are described in the *tab. 3*.
The boom had an articulation joint and it was considered interesting to separately control the movements of the section between the joint and the center and the movements of the section between the joint and the boom tip. As regards the application of the sensors to the boom, it is schematically described in *figure 4*.
The same rail used in laboratory was reassembled in field, reaching a 27 m length: the distance considered in the elaboration was 20 m. The cart moved on smooth surface of the rails along the tractor's longitudinal axis, without being affected by the soil unevenness. The cart function was to support the data acquisition system and an

horizontal, 6 m long bar, parallel to the boom.

Table 3
Characteristics of the nozzles used in the field test and test conditions

Type of nozzle		flat fan
Nozzle height	m	0.65
Nozzle flow rate	(l/min)	3.74
Distance between two nozzles	(cm)	50.00
	rad	1.13
Spraying angle (α)	°	65
	tg(α/2)	0.64
Spraying width	(m)	0.83
Travel speed	(m/s)	1.33
Acquisition interval (t_a)	(s)	0.05
Unit dose	cm^3/s	62.33
Nozzle dose*	cm^3	3.1167
Space in t_a at a speed of 1,33 m/s	m	0.067
Dose basic value**	mm	0.056

* *Quantity of liquid sprayed in t_a*
** *It results from the ratio between the "nozzle dose" (cm^3) and the surface (cm^2) sprayed by the nozzle during t_a at the travel speed. It is expressed in mm multiplying the result of said ratio by 10*

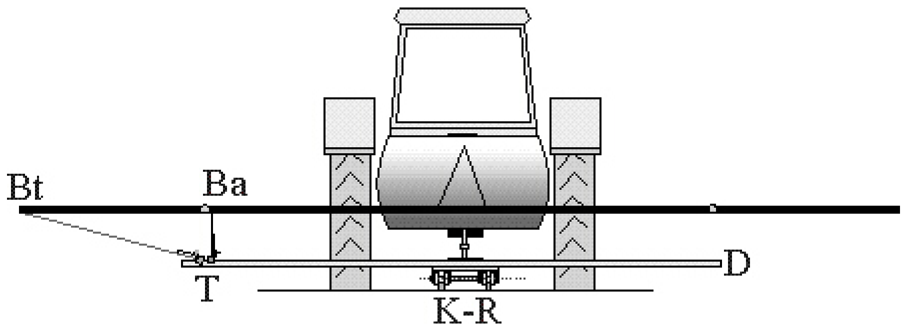

Fig. 4 - Scheme of the application of the transducer system to the boom in field tests. One group of sensors is applied near the boom articulation. The other group reaches the boom tip by means of a light, non extensible thread.
Ba - boom articulation; Bt - boom tip; T - transducers supported by the bar D parallel to the boom; K-R - cart rail system.

On the left edge of this bar the two groups of sensors were placed. One of them was right under the boom articulation, while the other could reach the boom tip by means of a very thin, light and non extensible thread.
The rail's longitudinal axis was the same as the tractor's. During each repetition the

tractor advanced at the velocity of 6 km/h, pulling the cart on the rail; while the transducers system recorded the movements of the two inspected points of the boom.
Considering the geometrical characteristics of the boom and nozzles, the movement data of the inspected points have been processed to calculate the distribution at ground level under the right side of the boom, along the 20 m distance.
To this purpose, the same procedure described in *annex A* was extended to all the nozzles of the right side of the boom. For each nozzle, the pattern of the transversal distribution has been calculated by increasing the distance from its central point of 50 mm each time.
As the right side of the boom comprehends 12 nozzles, said elaboration was repeated 12 times providing 12 matrices of data. Considering the 50 cm distance between contiguous nozzles, these matrices have been partially overlapped to reproduce the overlapping of the areas sprayed by contiguous nozzles.
This elaboration produced a bigger matrix of data; the area sprayed by the inspected sections of the boom can be represented as a grid having rectangular meshes: their transversal side is 50 mm long (as said above), while the length of the longitudinal side is based on the time of acquisition (0.05 s) and depends on the travel velocity of the tractor: if the velocity is 6 km/h (1.67 m/s), as in our tests, the resulting length will be 83 mm; each value of the matrix refers to one of said rectangles and provides the dose received resulting as the sum of the doses distributed by the nozzles that overlap in that point.

2. Results and discussion

2.1 – Laboratory tests

As said above, from the point of view of boom movements, the tests had the characteristic of repeatability when keeping the conditions of velocity and wheel size constant.
Figure. 5 shows the pattern of the longitudinal distribution, obtained by processing the movement data, compared with the distribution observed in the test tubes respectively, with unexcited and excited boom.

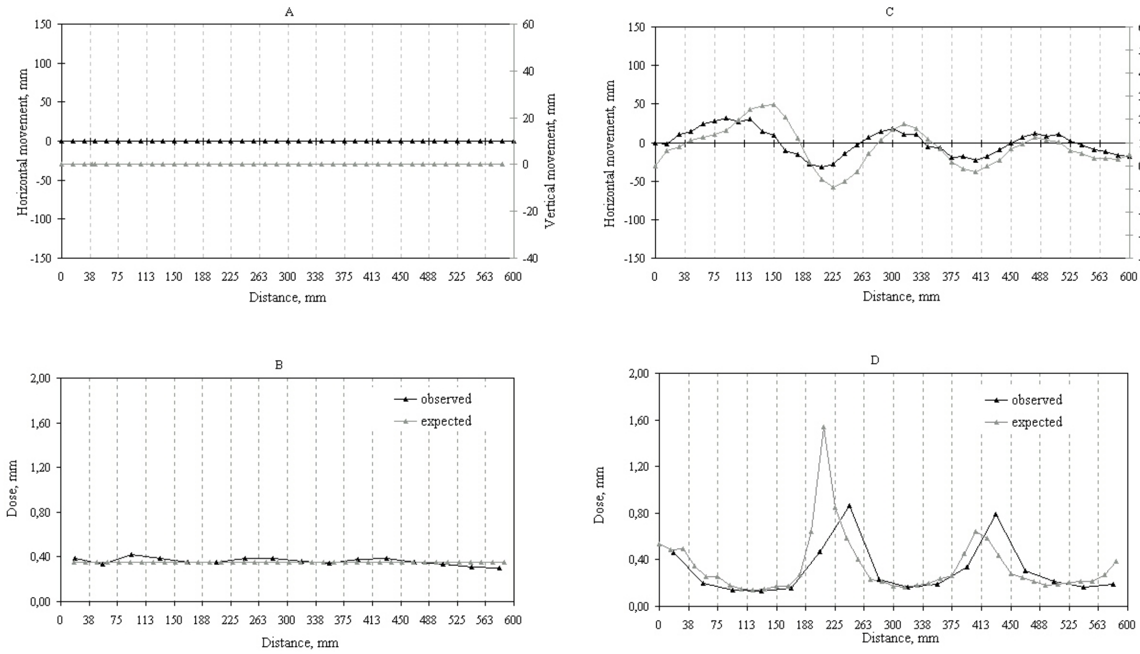

Fig. 5 - Tests in laboratory. The "distance" on X axis expresses the position of the test tubes grid under the nozzle. The grey dotted vertical lines correspond to the position of the transversal rows of the test tubes. ***a****, unexcited boom: as there is no contact between boom and wheel in this case, the diagrams of the movements show flat lines;* ***b****, longitudinal distribution with unexcited boom: the black line describes the longitudinal distribution as average of the 16 transversal rows of the test tubes; the grey line is the expected distribution. Since the boom has no movements in this case, the calculated distribution has a perfectly horizontal (constant) pattern;* ***c****, boom excited after the impact with the wheel. The diagram shows the horizontal (black line) and vertical (grey line) movements that occur in this case;* ***d****, pattern of the longitudinal distribution resulting from the movements*

Considering that the transversal distribution in the test tubes rows has a maximum in the center (under the nozzle) and decreases proceeding towards the edges, the comparison between the longitudinal patterns of the observed and expected distribution has been made comparing the mean values of the transversal rows of test tubes with the calculated values.

In unexcited boom conditions, the calculated and actual distributions have similar patterns (*figure 5-b*): the first is perfectly constant, since the data processing depends on the variations of the position of the nozzle, that do not occur in this case, while the second has some small variations probably determined by some working irregularity in the distribution system. The mean values of the distribution are similar.

The results of the tests with excited boom show some differences between the values of the observed and expected distribution, as shown in the diagram reported in *figure 5-d.* Nevertheless, they have a similar behavior with maximum and minimum values occurring in the same points.

As regards the transversal distribution, *figure 6-a* shows the pattern (average pattern of

16 rows) observed in the test tubes (excited boom), as *figure 6-b* reports the transversal distribution calculated by processing the movement data as described in the *Annex A* (the calculation has been made in correspondence of the test tubes position). The black horizontal lines in both diagrams represent the averages. Their values are similar.

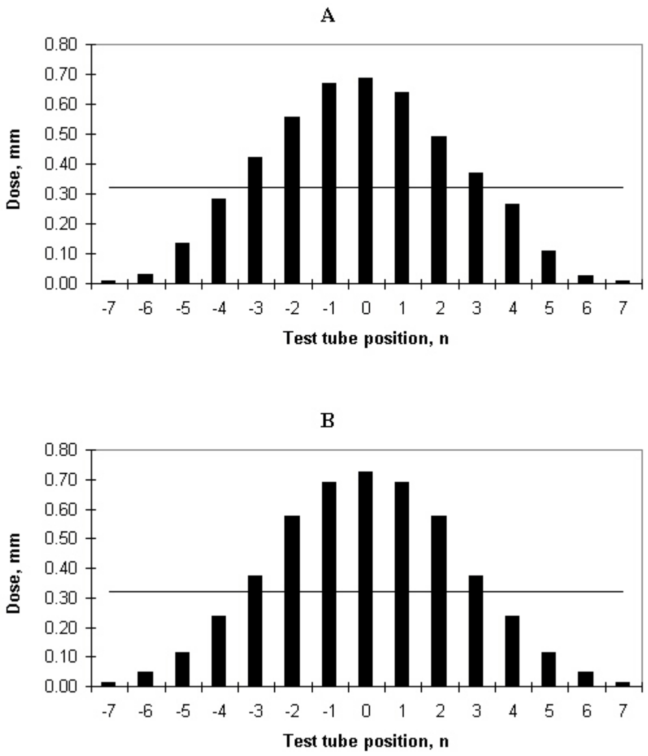

Fig. 6 - Transversal distribution under the nozzle used in the laboratory tests. In the X axis, "0" is the central point under the nozzle; the horizontal lines represent the average values. Each histogram consists of 15 bars that represent the 15 test tubes. A, transversal distribution observed in the test tubes. Each bar expresses the average of the 16 test tubes forming the columns of the grid shown in figure 3. B, average pattern of the expected transversal distribution calculated on the basis of the monitored movements and nozzle characteristics. The values have been calculated referring to the position corresponding to the 15 test tubes of each row.

Both the observed and expected distribution are represented by a matrix of data: each datum expresses the dose (in mm) distributed in the corresponding point of the grid. For the observed data, the matrix is represented by the values observed in the test tube grid. As to the expected data, the matrix refers to the area corresponding to the test tubes grid, but has a higher number of values depending on the travel speed and t_a: each value is defined as the result of the movement data processing (providing the average value of the transversal distribution) combined with the procedure described in the *Annex A*.
The *figures, 7, 8 & 9* report the graphical representation of said matrices. They refer to the tests with unexcited and excited boom and show the general pattern of the distribution in the area corresponding to the grid of test tubes.

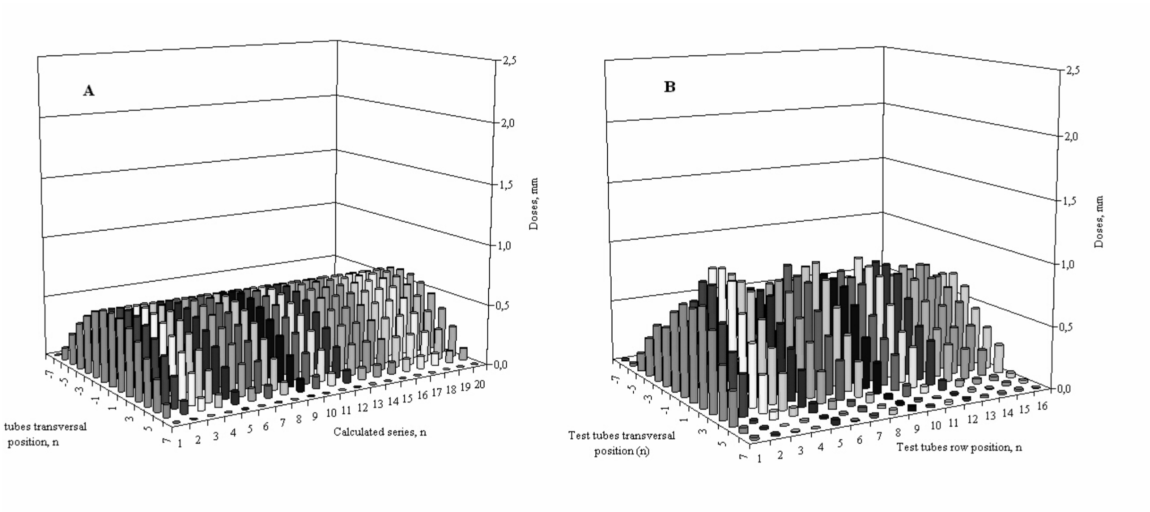

Fig. 7 - Tests in laboratory with unexcited boom. A) Expected distribution; B) Observed distribution

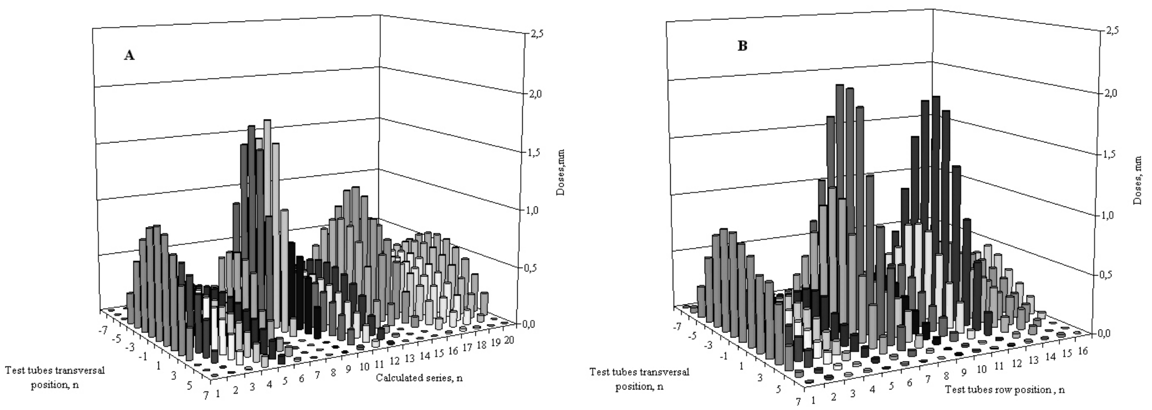

Fig. 8 - Tests in laboratory with excited boom. A) Expected distribution; B) Observed distribution

The data of the matrices underwent elaboration to calculate the averages, the standard deviations, the coefficients of variability (C.V.) and the variance. The results are reported in *table 4*.

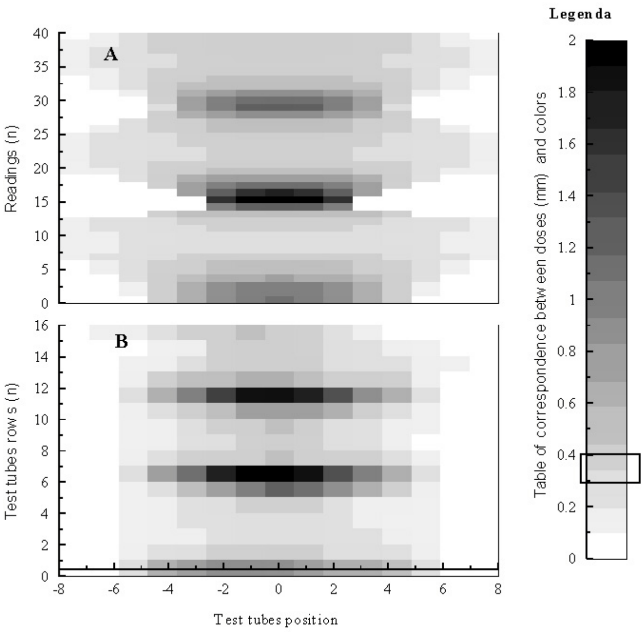

Fig. 9 - Map of the area corresponding to the test tubes grid. The elaboration of nozzle's movement data produced a matrix of values: each value corresponds to the dose received by a rectangle. In this diagram the doses are expressed by the intensity of gray to give an immediate idea of the quality of distribution. . The test tubes position on the X axis refers to the central point under the nozzle assumed as 0. The black rectangle on the legenda surrounds the interval around the average values of the doses A, expected: the transversal distribution (along each single row) has been calculated considering the same distances of the test tubes from 0 on the X axis; the longitudinal distribution (number of rows) depends on the acquisition frequency: that is why the number of rows is higher than for the observed; B, observed: pattern of the distribution observed in the test tubes. The contents of each test tube is the average of ten repetitions.

In the case of unexcited boom similar average values of expected and observed data can be noticed, as the other parameters show greater differences: theoretically, the total absence of movement produces a perfectly constant expected distribution (there is only a constant transversal variability determined by the application of the relation in *annex A* to reproduce the parabolic pattern), as calculated by mean of the described procedure; in practice, the test tube contents show small longitudinal and greater transversal variations as the grid moves under the boom, increasing the values of the standard deviation , of the coefficient of variation and of the variance.
These differences reduce in the case of excited boom and the said parameters assume similar values.

Table 4
Statistical considerations on the results of the laboratory tests

parameter	*average doses (mm)*			
	unexcited boom		*excited boom*	
	observed	*expected*	*observed*	*expected*
average, mm	0.36	0.35	0.31	0.32
st. dev, mm	0.30	0.21	0.39	0.38
C.V.	84.25	60.22	123.66	118.26
variance	0.09	0.04	0.15	0.15

4.2 - Field tests

The movement data of the two inspected points have been processed to obtain the pattern of the distribution of all the nozzles of the right arm of the boom along a 20 m distance. The diagrams in *figures 10 & 11* report, respectively, the behavior of the boom under suspended and unsuspended conditions, showing clear differences in the pattern of the considered parameters that are: the variations of the spraying height; the variations of the spraying width; the variations of the surface sprayed during the acquisition time; the variations of the doses distributed at ground level.

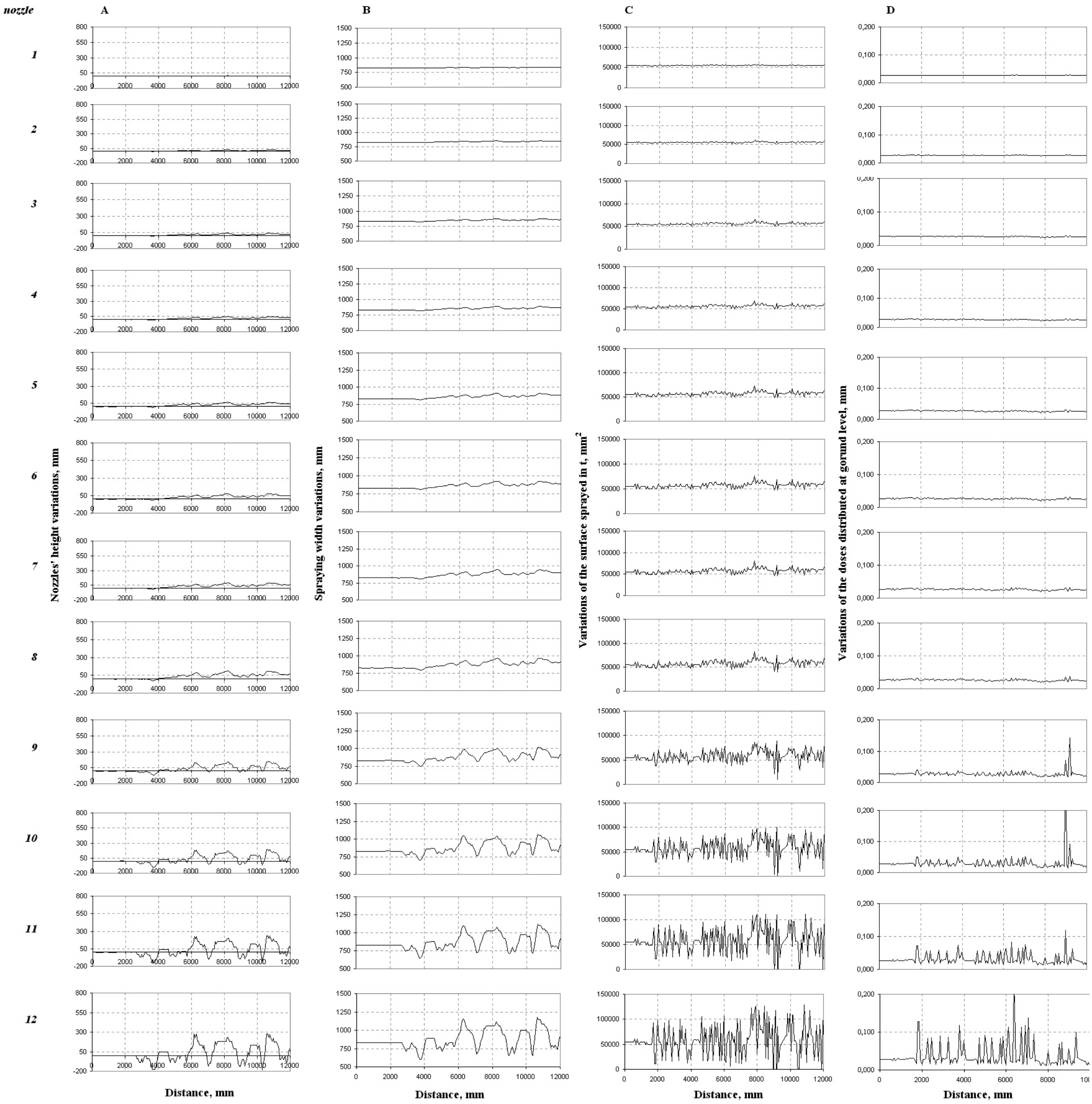

Fig. 10 - Tests with suspended boom: behavior of the 12 nozzles of the right arm. The numbers on the left side indicate the nozzle from the boom center to the boom tip. A, variations of the height of the nozzles; B, variations of the distribution width; C, variations of the surface sprayed by each nozzle during the acquisition time (t a = 0.05 s at 6 km/h speed); D, variations of the doses distributed at ground level.

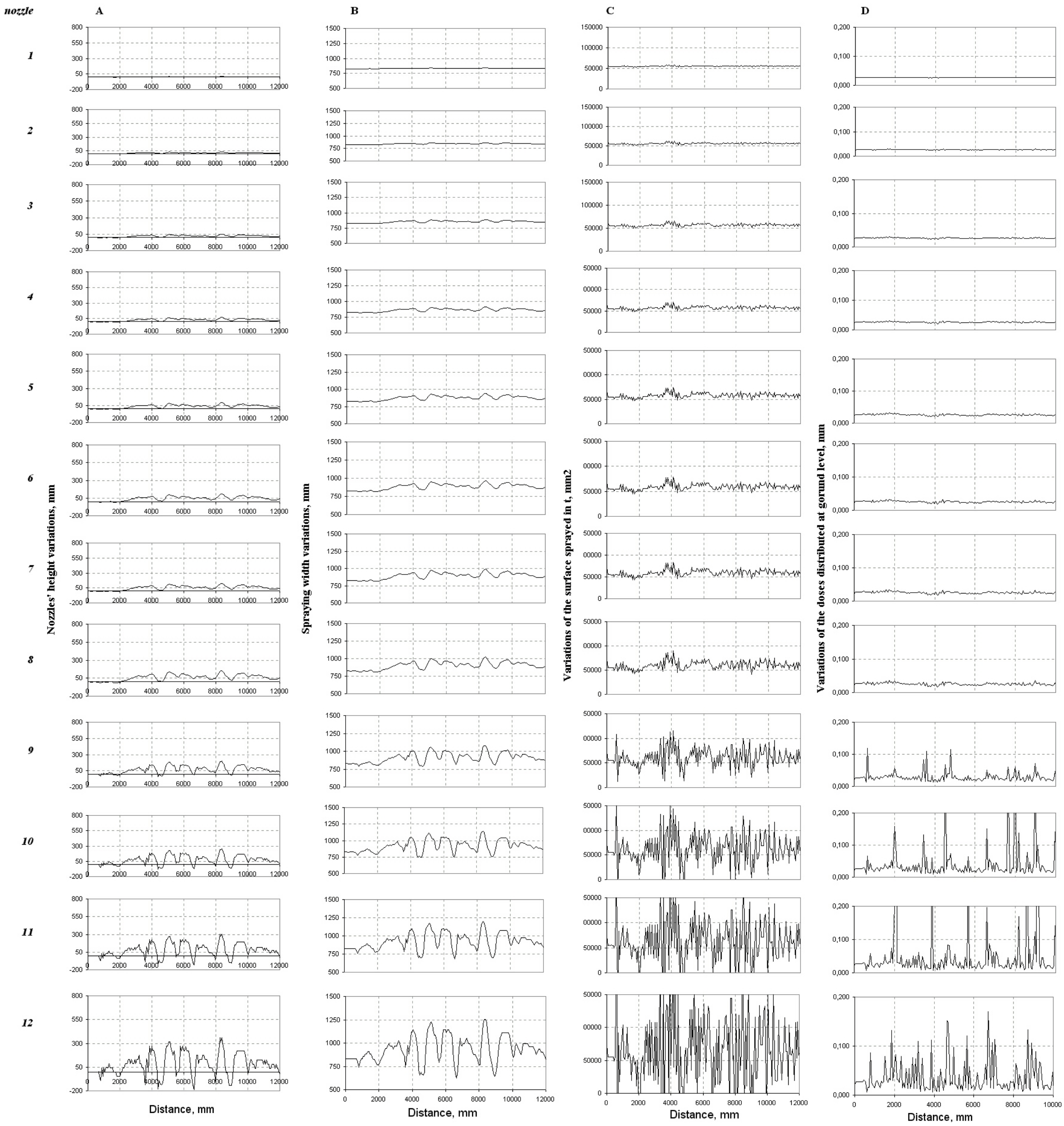

Fig. 11 - Tests with unsuspended boom: behavior of the nozzles of the right arm. A, variations of the height of the nozzles; B, variations of the distribution width; C, variations of the surface sprayed by each nozzle during the acquisition time (t a = 0.05 s at 6 km/h speed); D, variations of the doses distributed at ground level.

Said differences are testified by the statistical considerations reported in *tab. 5* that shows how the unsuspended boom reaches higher values for average, maximum, standard deviation and CV. Moreover, considering that 0.056 mm is the dose sprayed at constant velocity and without boom movements, *table 5* also shows the frequency (number and percent) of values inside the interval between 0.04 and 0.07 mm (0.056 +/-

25%): the choice of this interval is only an example. It will be more suitably determined on the basis of the results of a series of field tests. Said frequency is higher for the suspended boom.
The diagrams in *figure 12* report the maps of the distribution at ground level, for suspended and unsuspended boom, based on the *grid* of values determined as said in *4.2*. The values of the grid have been expressed as grey tones; increasing the value determines higher grey intensity.

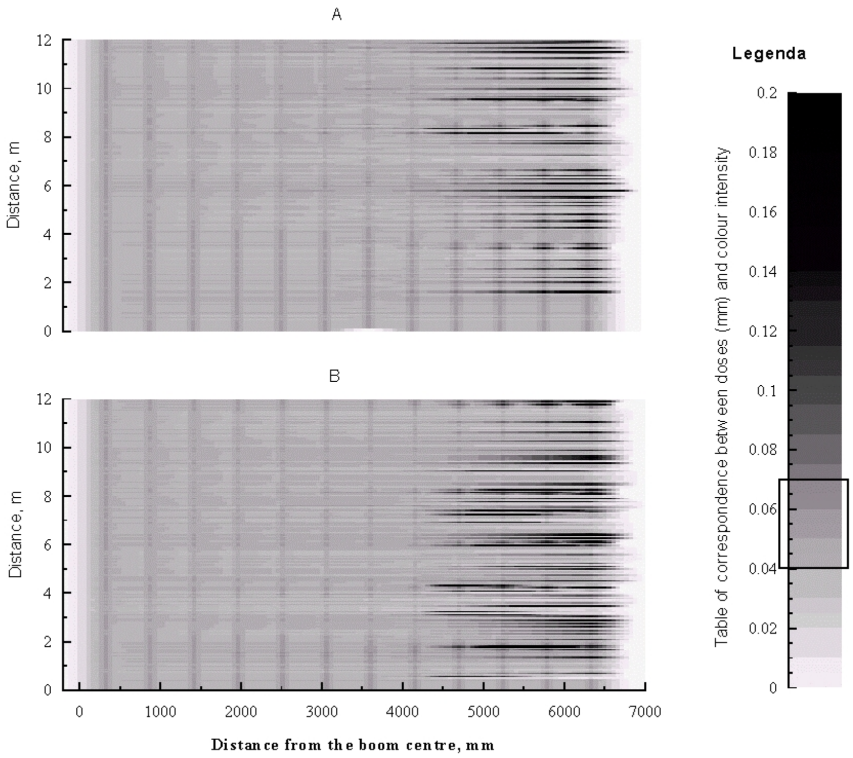

Fig. 12 - Map of the area sprayed by the right side of the boom during the tests. The area is represented by a grid. Its meshes divide the area into small rectangles whose dimensions are 50 83 mm. The data processing of each nozzle's movement data produced a matrix of values: each value corresponds to the dose received by a rectangle. In this diagram the doses are expressed by the intensity of gray to give an immediate idea of the quality of distribution. The black rectangle on the legenda surrounds the interval around the average values of the doses. A, suspended boom; B, unsuspended boom.*

The full range of values obtained in the data processing is too large to be adopted in the determination of the grey tones scale: *tab. 5* shows that the maximum doses obtained in the tests are 1.68 mm and 1.30 mm respectively for unsuspended and suspended boom, as the theoretic dose should be 0.056 mm. In order to obtain a map with a sufficient sensibility, we considered the range between 0 and 0.20 mm: it has been divided into 40 classes and to each class was assigned one tone of grey. The values over 0.20 mm are expressed by the color black.
This map gives an immediate information about the regularity of distribution determined by the steadiness of a boom sprayer.
Observing the diagrams, we can notice the presence, in both of them, of twelve longitudinal stripes slightly darker than the remaining areas. These stripes correspond to the central higher values of distribution under each of the twelve nozzles calculated along the 20 m distance.
In general, the distribution has a better pattern for the suspended than for the

unsuspended boom, but, considering the section between the center of the boom and the articulation (nozzles 1 to 7) we can notice quite a uniform distribution under both test conditions.
The section between articulation and boom tip (nozzles 8 to 12 from the center) shows alternating bright and dark transversal stripes, testifying the irregularity of distribution that is, anyway, clearly higher for the unsuspended boom.
The data reported in *table 5* testify the better behavior of the suspended boom, that presented lower values of maximum, average, standard deviation and coefficient of variation, while the number of values inside the interval 0.04-0.07 mm is higher.

Table 5
Some results of statistical elaboration of the data of field tests

parameter	*unsuspended boom*	*suspended boom*
Theoretic dose, mm	0.027	0.027
Average, mm	0.047	0.045
St. dev., mm	0.051	0.035
Maximum, mm	1.678	1.300
CV	108.01	78.82
Frequency *	19636	20604
Frequency**	75.13	78.83

**number of values inside the interval 0.04-0.07 mm*
***number of values inside the interval 0.04-0.07 mm in percent of the total number*

3. Conclusions

The horizontal and vertical movements of boom sprayers are among the causes affecting the quality of distribution. When a boom is perfectly working as regards the distribution system (pump, nozzles, etc.), its steadiness becomes a very important factor for the quality of distribution.
Through the elaboration of the movement data and considering the geometrical characteristics of the booms and of the adopted nozzles, it is possible to estimate the resulting distribution and to observe how the movements affect the quality of treatment.
The instrumental system, the equipment for its application and the data processing methodology described in this paper have been realized to estimate the effects of the steadiness of boom sprayer on the distribution under operating conditions.
This system can be used on all kinds of surfaces (field or track), but in order to compare the performances of different booms it would be convenient to define a standard test track having well determined characteristics.
It could contribute to a wide scale investigation of boom sprayers (both new and already in use), from the point of view of the steadiness. It could also be a useful instrument to extend the range of the certification activity adopted in Europe up to now only for the control of the distribution system, completing the investigation of the performances of this kind of machinery.

Annex A : simulation of the pattern of the transversal distribution

In order to simulate the actual pattern of the transversal distribution observed in the test tubes during the laboratory tests, it has been assumed that, for the transversal distribution, the relation between the dose in one point at ground and its distance from the central point under the nozzle is described by the equation of a parabola

$$y = ax^2 + bx + c \qquad (1),$$

where:
y is the dose (expressed in mm);
x is the distance from the central point.
The vertex of the parabola is on the Y axis and represents the dose in the central point ($x = 0$); the transversal distribution, referred to the Y axis, is symmetrical.
The parabola has its concavity below, determining negative values of the coefficient "*a*"; "*a*" is function of the co-ordinates of the *focus* and the position of the *directrix* of the parabola that are not known. For this reason, "*a*" has been calculated as follows:

$$a = m * d_m^2 \qquad (2),$$

where:
d_m : is the calculated dose (average transversal dose, determined row by row, taking into account the nozzle height variation).
m: is a coefficient arbitrarily determined in order to give "*a*" the negative sign and to calculate a new coefficient "*a*" for each value of "d_m" resulting from the elaboration of the movement data. The function of "*m*" is to adapt the behavior of the calculated transversal distribution to the behavior observed in the test tubes rows. For this reason each "*m*" value can only be applied to one type of nozzle. The value of "*m*", determined for the type of nozzle used in these tests, allows to automatically determine a new equation to describe the distribution of each row.
For a "d_m" increase, the resulting coefficient "a" determines the decrease of the maximum distance "*x*" from the central point (intersection between the parabola and the X axis), reproducing the behavior of the distribution (when the height of the nozzle decreases, at a constant velocity, the liquid sprayed in the time t_a is distributed on a surface whose width decreases as well, increasing the dose value).

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