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EQUIVALENCE OF THE CRITERIA OF ASSESSING RESULTS OF TESTS IN LEGALIZING CROP SPRAYERS

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ABSTRACT

The paper presents results of estimating the technical state of spray nozzles placed on a spray boom hanging over a patternator. Results of laboratory tests were analyzed considering the criteria of estimation binding in Poland in reference to electronic and manual patternators. Theoretical considerations are used to determine the equivalence of those criteria.
The studies found out nonequivalence of the criteria of estimating the results for electronic and manual patternators and their incoherence with the criteria binding in the quality systems. The binding criteria make it possible to take divergent decisions in legalizing the same sprayer.
Key words: patternator, criteria of assessment, distribution of the fall of the sprayed liquid

INTRODUCTION

The legal obligation to carry out periodical tests of the technical state of crop sprayers make it possible to improve the quality of the protective treatments of plants and to limit the dangers for the natural environments caused by the improper use of pesticides. These tests allow for eliminating the equipment that is technically worn out. In order to fulfil these goals it is necessary to conduct studies using the methods that are ecologically safe and that will enable the achievement of explicit, reproducible information useful for the agricultural practice.

Special organizational units were called to control the technical state of crop sprayers. They work on the basis of authorization given by the District Inspectorates of Plant Protection and on the basis of procedures and criteria of estimating the results of tests as determined by the Chief Inspectorate of Plant Protection (GIOR) [11]. The legal basis for such studies was established in *Dziennik Ustaw* No. 90 from 1995 and No. 30 from 2001 [12, 13]. The binding criteria of estimating the sprayers raise no doubts except for the tests concerning the technical state of nozzles carried out with the use of patternators.

PURPOSE AND SCOPE

It was assumed, that the criteria of estimation for the same methods of measuring the same phenomenon but using different manners of reading the results have to lead to the same (or similar), methodologically comparable results of final studies.

The purpose of the studies was to compare the criteria provided in an Instruction GIOR [11] of estimating the quality of the work of nozzles tested with a manual and an electronic patternators. These patternators ensure the fall of the liquid measured by the nozzles to measurement vessels. The level of the liquid is determined visually or by electronical system. According to the currently binding procedure of estimating the technical state of nozzles used in crop sprayers there are two methods of measurement and three different criteria of estimating the test results [11].

One of these methods is to measure the intensity of the unit outflow for each nozzle, and then to compare the result of measurement with the nominal outflow. Using this method it is recommended to measure the pressure in each section of the sprayer boom. The results achieved in this manner are explicit and comparable [3, 5].

The other, equivalent method is to determine the distribution of the transverse irregularity of the fall of sprayed liquid on a manual or an electronic patternators. Determination of the irregularity of the fall of the sprayed liquid is performed on the basis of coefficient of variation or deviation from the mean value for the amount of liquid collected in the measurement vessels of the patternator.

The studies carried out earlier showed differences in estimating the same sprayer using a manual and an electronic patternators [6]. The results achieved so led to a hypothesis about nonequivalence of the criteria of estimating the results of tests performed on the nozzles evaluated using patternators.

According to the criteria binding in this case [11]:

a. a positive result for an electronic patternator is the obtained 15% value of coefficient of transverse irregularity of the fall of the sprayed liquid (C.V.) [11],
b. a positive result for manual patternator is a 15% deviation from the mean value determined for the amount of liquid contained in all measurement vessels provided that in not more than 15% of these vessels the result of the reading should be beyond the tolerance (is beyond the mean value) [11].

On the basis of experimental results and the theoretical considerations, an analysis was made of the equivalence and the univocal character of the binding criteria of estimating the test results for the nozzles using an electronic and a manual patternators. It was also found out whether the adopted criteria make it possible to fulfil the quality requirements in the process of testing crop sprayers, and what are the possible consequences of those criteria for the agricultural practice.

The studies did not consider the ecological dangers occurring when patternators are used to test the nozzles, including the dangers for the workers who examine the sprayers [5]. It was also assumed that the other sprayer units are positively evaluated.

METHODS

The studies were carried out on a measurement site (electronic patternator meeting the requirements ISO 5682-2) fig. 1. at an authorized laboratory ARC – Agricultural Engineering Department, Gembloux – Belgium. The conditions of the tests are given in table 1.

Fig. 1. Electronic patternator CRA Gembloux, Belgium

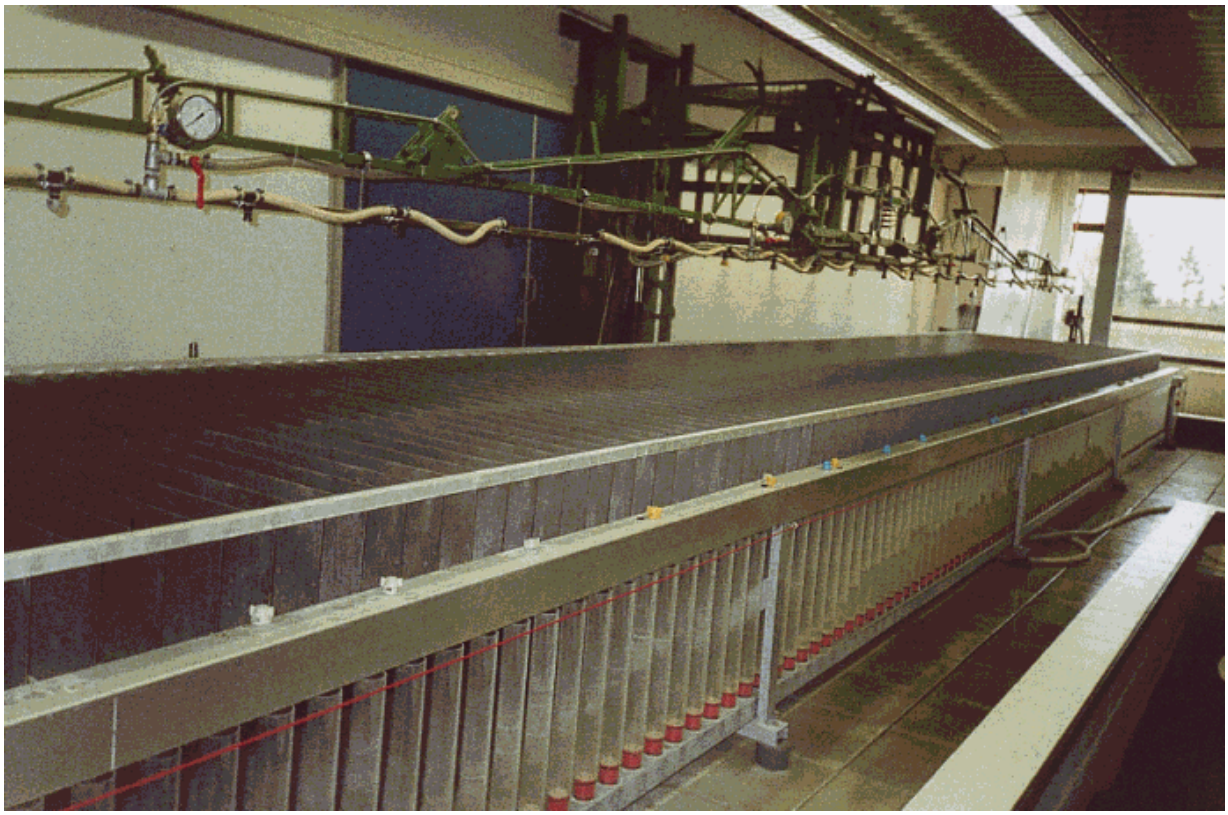

Table 1. Characterization of the conditions of tests

Specification	Measurement units	Measurement results for nozzle KŻK Kranj
Patternator	type	electronic (fig. 1)
Number of tested nozzles	items	10
Material for nozzles		brass
Hours of work of nozzles till the tests	hours	50
Nominal flow rate	dm^3/minute	1.48
Flow rate in tests	dm^3/minute	1.62
Spacing of nozzles on the spray boom	mm	500
Height of nozzles above patternator	mm	500
Working pressure	MPa	0.3
Room temperature		
– before the tests – after the tests	°C °C	18.00 17.80
Relative humidity		
– before the tests – after the tests	% %	87.0 96.0

Bronze slit nozzles KŻK Kranj, which had worked for 50 hours (in field conditions) were tested. The wear-out degree for the nozzles was determined in % (table 2) by measuring a unit rate of the liquid outflow and referring the results to the rate of the nominal outflow. Increase of the outflow rate of more than 10% of the nominal outflow was considered as the value beyond tolerance [11].

Table 2. The measurement results of the rate of unit outflow and estimation of the degree of the nozzles' wear-out

No. of nozzle	Rate of nozzle outflow		% increase of outflow rate	Rate of outflow beyond tolerance (X)
	nominal	achieved		
1	1.48	1.566	5.8	
2	1.48	1.533	3.6	
3	1.48	1.548	4.6	
4	1.48	1.747	18.0	X
5	1.48	1.603	8.3	
6	1.48	1.650	11.5	X

7	1.48	1.719	16.1	X
8	1.48	1.498	1.2	
9	1.48	1.781	20.3	X
10	1.48	1.542	4.2	
mean	1.48	1.619	9.4	

The tested nozzles were mounted on the measurement site, and then a number of successive measurements were performed preceded by changing the location of the nozzles in the nozzle bodies. The studies found out changes both in the coefficient of the flow irregularity (C.V.) of the sprayed liquid and in the volume of liquid in the measurement vessels.

The further analysis took the sixth result (table 3). On the basis of which it can be stated, that in the case of considering the estimation criteria binding in legalizing the sprayers the result of the final evaluation was not uniform, since it was positive for an electronic patternator and negative for a manual one. In order to find out the level of equivalence of the adopted criteria of estimation, this case was analyzed theoretically, considering the fundamental principles of mathematical statistics.

Table 3. Assessment of the technical state of nozzles KŻK Kranj considering changing the location of nozzles on the spray boom and the binding criteria of assessment

Specification	Results from successive measurements					
Sequence of measurement	1	2	3	4	5	6
No. of tested nozzles	10	10	10	10	10	**10**
No. of tested measurement vessels (grooves)	45	45	45	45	45	**45**
Amount of liquid in measurement vessels – mean value (ml)	398.9	408.5	403.5	406.9	402.5	**397.6**
Coefficient of variation C.V. (%)	17.96	18.01	17.16	17.00	17.14	**14.36**
Number (%) of measurement vessels in which the amount of liquid was beyond tolerance <15%> of the mean value	9 (20)	9 (20)	13 (29)	12 (27)	12 (27)	**13 (29)**
Amount of ml of liquid in vessels determined with ±15% mean value: *TG* – upper tolerance *TD* – lower tolerance	 458.7 339.1	 469.8 347.2	 463.4 343.2	 467.9 345.8	 462.9 342.1	 **457.2** **337.9**
Standard deviation ml, (σ)	71.65	73.56	69.30	69.27	69.0	**57.11**
Range of tolerance for ±15% deviation from the mean amount of liquid in vessels, ml	119.6	122.6	120.2	122.1	120.8	**119.3**
Achieved technical tolerance for tested nozzles, ml (= 6σ)	429.9	441.4	415.8	415.6	414.0	**342.7**
Perspective capacity of fulfilling quality requirements C_p, (min. C_p > 1.3)	0.28	0.28	0.29	0.29	0.29	**0.35**

Besides, the studies tested the ability of the teams examining the sprayers to interpret the results in a reliable way, keeping all the quality requirements. The C_p coefficient, determining the total quality capacity of the process [8] was calculated as follows:

$$C_p = \frac{TG - TD}{6\sigma} \qquad (1)$$

where: *TG* and *TD* signify the upper and lower tolerance respectively, expressing a 15% deviation from the achieved mean value of the fall (X_{sr}), while σ signifies standard deviation.

In this case, it was analyzed how many times the adopted range of natural tolerance, which is 6σ, is contained within the achieved technical tolerance. It was assumed that the index C_p>1.33 will mean stabilization of the fall of the sprayed liquid to particular grooves of the patternator, with simultaneous assurance of certain (25%) boundaries of tolerance that satisfy the quality expectations [8]. The analysis did not determine the accuracy of the distribution of the measurement results.

RESULTS

Laboratory studies showed (tables 1 and 2), that the use of worn-out nozzles does not keep the comparable quantity of the sprayed liquid on the model (one groove) surface of the patternator. It was found out (table 3), that exchanging the succession of the nozzles placement in the nozzle bodies of the boom affected the C.V. and the number of measurement vessels, where the amount of the collected liquid exceeded (+ or -) 15% deviation from the mean value. The deviation was determined as upper (*TG*) and lower tolerance (*TD*).

In measurement no. 6, which was accepted for a detailed analysis (table 3) coefficient C.V. is 14.36%, and according to the estimation criteria for an electronic patternator this result allows the sprayer to be further used.

Estimation of the same results considering the criteria referring to a manual patternator was negative. In this case, the amount of liquid in 28.9% of the measurement vessels was inconsistent with the estimation criteria for manual patternators and the same sprayer should not be allowed for further use. Not a univocal result shows, that while evaluating the sprayers the adopted criteria of estimation are not equivalent with the use of electronic and manual patternators.

The above statement was also justified by theoretical considerations, which assumed that the spray boom working in the conditions according to the binding procedure is evaluated. For the sake of theoretical considerations certain assumptions and model designations were adopted, where X_i means the value of outflow from the *i*-th groove (in the further part index *i* will be omitted).

Assumption: It is generally assumed that the studied feature *X* has a normal distribution, which is parameterised with the mean value and the variance. These values were marked μ and σ^2 respectively, and each of these values is positive, i.e. μ>0 and σ^2>0.

The assumption, that the studied feature *X* is treated as a random variable with normal distribution means that

$$P(a \le X < b) = \frac{1}{\sigma\sqrt{2\pi}} \int_a^b e^{\frac{-(x-\mu)^2}{2\sigma^2}} dx \qquad (2)$$

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for any pair of real numbers *a* and *b*. Because the integral in formula (2) is not elementary, to calculate it the tables of so-called Laplace's function ϕ are used. We use the well-known fact, that the standardized variable

$$U = \frac{X - \mu}{\sigma} \qquad (3)$$

has normal distribution with the mean value 0 and variance 1. The tables give the values of

$$\phi(\alpha) = P(U < \alpha) \text{ for } \alpha \geq 0$$

Adopting the assumption above and taking into consideration the fact, that Instruction [11] in the chapter on the studies of the equivalence of the fall of the sprayed liquid gives two estimation criteria that should be equivalent, the range of equivalence of these two criteria was marked. After considering the criteria determined in Instruction [11] it was found out that:

Criterion I (for the electronic patternator), where the coefficient of variation (C.V.) should not exceed the value of 15%. This means that the critical value of quotient $\nu = \frac{\sigma}{\mu}$ does not exceed 0.15, or symbolically

$$\nu = \frac{\sigma}{\mu} \leq 0.15. \qquad (4)$$

Criterion II (for the manual patternator), where not more than 15% of the measurement vessels should show deviation form the mean value greater than 15% (presumed 15% of the mean value). A formal recording of this condition in terms of the calculus of probability should have the following shape:

$$P(|X - \mu| > 0.15\mu) \leq 0.15 \quad (5)$$

which is equivalent to

$$P\left(\left|\frac{X - \mu}{\sigma}\right| > 0.15\frac{\mu}{\sigma}\right) \leq 0.15 \quad (6)$$

This notation can provide the critical value for the variation coefficient $\nu = \frac{\sigma}{\mu}$.

Because the random variable $U = \frac{X - \mu}{\sigma}$ has symmetrical distribution towards zero, the last condition can be recorded in the following form:

$$P\left(U > 0.15\frac{\mu}{\sigma}\right) \leq 0.075 \quad (7)$$

or equivalently

$$P\left(U < 0.15\frac{\mu}{\sigma}\right) > 0.925 \quad (8)$$

This notation makes it possible to read from the tables of normal distribution [10] value u_0 and this value is

$$P(U < u_0) = 0.925 \quad (9).$$

This is number $u_0 \approx 1.44$. Confronting the result with formula (8) the critical value v_0 is obtained for the coefficient of variation (C.V.): $v_0 \frac{0.15}{u_0} \approx 0.104$.

Therefore, Criterion II determined by means of formula (5) is not equivalent to Criterion I, since it requires the variation coefficient of 10.4%, and not 15%, which follows from Criterion I (4).

Lack of equivalence of the adopted criteria found in laboratory and theoretical studies for the estimation of the technical state of the evaluated nozzles on electronic and manual patternators, can limit the fulfillment of quality requirements in the course of studies.

This phenomenon was in a general range determined through calculating the so-called coefficient of total quality capacity of the process (C_p), cf. table 3. The results showed, that the quality requirements were fulfilled in none of the six studied variants of the work of the spray boom with the nozzles mounted on it.

The formation of C_p coefficient within the range 0.28-0.35, instead of at least 1.33 means, that this process does not fulfil the quality requirements. Accidental variability is greater than the marked range of tolerance. In the sixth analyzed measurement it was found out, that the technical tolerance (6σ) is by 2.9 times greater than the adopted natural tolerance (limited by the lower and upper tolerance), and about 4 times greater than the tolerance accepted in estimating the process according to the requirements of quality systems (C_p=1.33).

It can be stated in this case, that the process is out of control and the sources of its variability should be sought in excessive use of some of the nozzles (table 2). The worn out nozzles are characterized by increased rate of the unit outflow, which – in turn – affects the high standard deviation for the liquid outflow as referred to the adopted range of tolerance.

DISCUSSION

The technique of plant protection is one of the treatments, that have a special importance for precise agriculture. The fundamental role in these treatments is played by limiting the chemical preparations for plant protection and their precise spread on the protected area. This

work can be done by means of technically efficient tools, the quality of which will be submitted to explicit, comparable and methodologically accepted criteria of estimation.

The issue of quality and reliability of the control tests of the equipment for plant protection is raised by a number of authors, some of whom prefer effective visualization of the tests [1, 2, 4], and some – their usefulness for the agricultural practice and limitation of the dangers for man and the natural environment [3, 5, 9].

In the case of obligatory tests for the equipment of plant protection according to Instruction GIOR, special tests are performed for the nozzles, although there is no obligation for them to have a certificate before they are introduced to the market. These tests are carried out by means of two equivalent methods, which enable different degrees of explicit and practically useful estimation of the technical state of nozzles.

The studies both evaluated the two binding methods and determined the degree of equivalence of the estimation criteria for the test results. For this purpose, 10 nozzles of the same type were examined, four of which were in bad technical condition (table 2). According to the binding criteria of assessment in accordance with the method of the of the unit outflow rate, the nozzles exceeding 10% of the nominal outflow had to be exchanged, or a negative result had to be accepted.

Further studies on the above set of nozzles were aimed at checking whether a similar result would be achieved in the studies carried out by means of nonequivalence of the fall of the sprayed liquid with the use of electronic and manual patternators.

It was found out (table 3), that different results were achieved in each of those variants. Those results – next interpreted according to the binding criteria – gave different results of the final evaluation. Those were sharper for the manual patternator (distinctly negative) than for the electronic one (one positive result).

The character of studies with the use of patternators, neither makes it possible to provide explicit estimation of the quality of the treatment nor gives possibilities to indicate and then eliminate the faulty nozzles. In the course of tests, it is necessary to perform visual evaluation of the work of particular nozzles. Moreover, exchanging the location of the nozzles in the nozzle bodies causes a change in the C.V., which in the present studies ranged from 18.01 to 14.36%.

In practice, these are not the tests of the technical state of nozzles but only evaluation of the spraying quality for the spray boom, with a given manner and succession of fastening the nozzles. It follows from the studies of other authors, that assessing a patternator can provide a positive result despite decreasing the liquid outflow for one nozzle by 67% [9]. Besides, the result of these studies can be interpreted according to two nonequivalent criteria of estimation.

Nonequivalence of the assessment results in laboratory studies was analyzed theoretically and it was shown, that for the adopted criteria the results with manual patternators would be sharper by about 4%. If the fact is taken into consideration, that qualification tests refer to the sprayers that have already been used, in which the nozzles are generally worn out to some extent, then the differences in the criteria of estimation should be considered to be significant. In order to balance the assessment criteria C.V.=10% can be adopted for the electronic patternator, with the same criteria of assessment for the manual one.

The studies also evaluated the technical state of nozzles on the basis of a method of measuring the rate of the unit outflow of the liquid, and referring the results to the nominal outflow (table 2). The results enabled an explicit evaluation of the work of each tested nozzle and pointed at the nozzles, that did not fulfil the requirement. The nozzles whose rate of the outflow does not exceed 10% of the nominal outflow are considered to fulfil the quality requirements. This criterion is confirmed by the studies conducted at the Industrial Institute of Agricultural Machines in Poznan (PIMR). Those studies showed, that the nozzles keeping the nominal rate of the unit outflow also achieve good parameters of the transverse nonequivalence of the distribution of the fall of the sprayed liquid (C.V.) [7].

Nonequivalence of the assessment criteria for the methods of controlling the technical state of nozzles with electronic and manual patternators suggests a more general conclusion, that the capacity of the teams conducting tests on sprayers by means of assessing the nozzles should be questioned.

Quality requirements determine a certain safety margin in the formation of process variability, that in the studied case has to consider the range of tolerance adapted to the technical parameters of the work of nozzles used in agriculture. The necessity of keeping this margin follows from the changing parameters of the work of the spray boom and the variability of the working conditions in the treatments of plant protection. Mechanized technologies of production should take into consideration the conditions connected with the work of the machinist, weather, the type of the area, the canopy of plants, etc.

It is assumed, that the minimum margin of safety should be 25%, that is C_p=1.33 [8]. The achievement of the value C_p=1.33 shows, that as early as on the stage of laboratory tests the evaluation of the stability of the fall of the sprayed liquid cannot fulfil the quality requirements. This is caused by too narrow, i.e. 15%, range of tolerance for the deviation from the mean value in reference to the achieved standard deviation. It follows from the studies, that with a positive assessment for the electronic patternator this range is three times greater. In this case, standard deviation should not exceed 13% of the adopted range of tolerance of the deviation from the mean value. Such indexes of the quality of the nozzles' work allow a very high (about 5%) coefficient of variation, but they can be achieved with the nozzles of high technical parameters.

CONCLUSIONS

Controlling the technical state of crop sprayers in Poland calls for an estimation of the quality of work of the nozzles, which should be done on the basis of two equivalent methods, namely assessing transverse nonequivalence of the fall of the sprayed liquid on patternators or assessing the unit outflow rate of liquid in reference to the nominal outflow for a given type of nozzles.

The studies carried out with patternators give only a general (mean) assessment referring to the work of all nozzles mounted on the spray boom. The results achieved in this case are not explicit or reproducible, because they can undergo change after changing the sequence of fastening the nozzles on the spray boom. On the other hand, nonequivalent criteria of assessment for electronic and manual patternators practically make it impossible to provide the correct interpretation of the test results.

The adopted criteria of assessment cause, that the studies on patternators are conducted in the conditions of lack of equivalence between the technical parameters of the nozzles' work, the character of the examined phenomena and the methods of studies used for their evaluation. These studies generally do not consider the fact, that the binding procedures constitute an ecological danger, also for the workers examining the sprayers [5]. Considering all these conditions limits or practically eliminates patternators from periodical tests of the technical state of nozzles in crop sprayers, that have already been in use.

Evaluation of the technical state of nozzles by means of the other method (measuring the rate of the liquid outflow from each nozzle) allows for explicit, reproducible and practically useful results. The present paper refers to other authors' studies, from which it follows that the nozzles keeping the accepted rate of the liquid outflow ensure good quality of work as well [7]. This method does not bring any ecological threats and its further improvement will enable attestation of nozzles even before they are introduced to the market.

The preliminary studies were aimed at drawing the attention to the need of introducing the estimation criteria, that provide explicit, reproducible, ecologically safe and practically useful results of testing the nozzles. These methods should serve reasonable management and utilization of the agricultural production space, that is why they have to be assessed in a wide spectrum of conditions and on the basis of equivalent criteria adapted to the character of the examined processes.

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