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Mathematical model of cross-distribution non-uniformity for twin flat nozzle

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Abstract: *Mathematical model of cross-distribution non-uniformity for twin flat nozzle.* This study sets forth an analysis of the results of tests of cross-distribution uniformity for twin flat nozzle. Based on the results obtained, a mathematical model of non-uniformity was elaborated for twin flat nozzle, depending on the height and angle of the boom and the operating pressure of the liquid. The model enables assessment of interactions between the factors tested and their impact on the cross-distribution non-uniformity.

Key words: spraying machine, twin flat nozzle, cross-distribution non-uniformity

INTRODUCTION

The plant protection operation is a crucial element of the entire production cycle. Its abandonment or improper performance results in lower yields, or may even draw a line through the whole year's work. The final effect depends on a number of technical, technological, climatic and biological factors. The required effectiveness of the operation is strictly connected with obtaining a high degree of coverage of the plants sprayed, which highly depends on the nozzles used and the conditions of the spraying operation.

The spraying coverage ratio can be improved through the use of twin flat nozzle. The specificity of their operation allows to increase the liquid coating on vertical parts of the plants with concurrent elimination of excess coverage of the upper surfaces [Szewczyk et al. 2011]. With the operation, the working speed of the sprayer grows without any significant reduction of coverage of the surfaces sprayed [Szewczyk and Łuczycka 2011]. The working parameters should be maintained within the required range during the operation. This applies, in particular, to the sprayers used and the liquid's working pressure, on which the droplet size and spray drift potential depends [Hołownicki and Doruchowski 2006b, Nuyttens et al. 2007, Czaczyk 2012, Dorr et al. 2013, Wang et al. 2015]. Change in the operating height or uncontrolled boom deflection will cause: increase of the spray non-uniformity ratio, excessive spray drift and ecological hazards to adjacent crops [Hołownicki and Doruchowski 2006a, Nowakowski 2005, 2006a, 2007b]. With the appropriate selection of the spraying technique and the sprayer working parameters, plus the use of additives that improve physical and chemical properties of the liquid, it may be possible to reduce the dose of the herbicides and the impact of droplet drift on the natural environment, without deterioration of the weed eradication effectiveness [De Schampheleire et al. 2009, Kierzek et al. 2009, Ferguson et al. 2016].

Laboratory tests will make it possible to determine the range of changes of the cross-distribution non-uniformity factor (*CV*) for variable operating conditions. In this way, a better insight into the phenomenon will be obtained and it will be possible to elaborate a prediction model [Nowakowski 2006b, Parafiniuk et al. 2011, Parafiniuk and Tarasińska 2013]. Therefore, the aim of the actions undertook was to elaborate a mathematical model of cross-distribution non-uniformity for an active boom fitted with twin flat nozzle in variable working conditions. The model will be used for predictions of the non-uniformity factor depending on the changes in the liquid pressure, height and angle of the boom.

MATERIAL AND METHODS

The tests were carried out in laboratory conditions, with the use of a fixed power-driven field sprayer (variable-speed transmission). Twin flat nozzle TJ 60 110 06 VS were used for the tests, mounted along a four-meter long section of the boom, with a spacing of 0.5 m. The measurements of the cross-distribution non-uniformity factor were performed with an automatic Hardi Spray Scanner table, in accordance with the methodology described in the instruction manual and standard ISO 5682-3:1997 [Miszczak 2000, Nowakowski 2004]. The slot table used is suitable for sprayfall collection from the area of 1.2 m^2.

Measurements were performed at the liquid's working pressure between 0.2 and 0.4 MPa, every 0.05 MPa. The inclination of the boom was also changed, within the range from 0 to 5°, every 1°, while the boom's height above the slot table varied from 0.4 to 0.6 m, every 0.1 m [Nowakowski and Ośko 2016]. The measurements were repeated three times for each combination of variables. The test results were obtained through statistical analysis performed in Statistica v. 12, with ANOVA and Duncan's multiple comparison tests. The mathematical model was elaborated based on non-linear regression.

TEST RESULTS AND DISCUSSION

Based on the results of the three-way analysis of variants, it can be concluded that the factors analysed: height and inclination of the boom and the liquid's working pressure, had a highly significant statistical impact on the diversification of the cross-distribution non-uniformity, as the results of the Fisher-Snedecor distribution (F-distribution) equalled $F_{v1=2,\ v2=180} = 2083.69$, $F_{v1=5,\ v2=180} = 1579.45$ and $F_{v1=4,\ v2=180} = 189.51$, respectively, all given the critical significance level $P < 0.0001$. Additionally, major interactions were discovered between the factors tested: height and angle ($F_{v1=10,\ v2=180} = 1119.54$ with $P < 0.0001$), height and pressure ($F_{v1=8,\ v2=180} = 74.57$ with $P < 0.0001$), angle and pressure ($F_{v1=20,\ v2=180} = 29.42$ with $P < 0.0001$) and height, angle and pressure ($F_{v1=40,\ v2=180} = 7.54$ with $P < 0.0001$).

Based on Duncan's test (Table 1) it can be concluded that each and every change in the boom's working height by 0.1 m affects the value of cross-section non-uniformity factor, whereas the lowest values were observed for the height of 0.5 m. The tests of individual single steam-jet sprayers showed that a change in the working height by 0.4–0.6 m led to *CV* reduction accompanying the growing height of the boom [Lodwik and Pietrzyk 2014]. Nevertheless, as presented by field tests, together with the boom height growth up to 0.75 m, pressure increase to 0.3 MPa and wind speed of 2.4 m·s^{-1}, the overall liquid drift grew by over 75% [Świechowski et al. 2013]. Boom's deflection within the plane perpendicular to the ground from 0° to 1° does not cause changes in the non-uniformity factor, thus creating a homogenous group. Further deflection of the boom leads to isolation of other homogenous groups, i.e. significantly differentiates changes in the cross-distribution non-uniformity factor, which grows by 4.50 to 9.07% on average. The above is confirmed by research carried out by

TABLE 1. Division of cross-distribution non-uniformity values into homogenous groups based on Duncan's test according to: height and angle of the boom and working pressure of the liquid

Specification	Amount of substance	Average *CV* [%]	Homogenous group				
			1	2	3	4	5
Boom height [m]							
0.4	90	7.449			×		
0.5	90	4.825	×				
0.6	90	5.389		×			
Boom angle [°]							
0	45	4.606	×				
1	45	4.499	×				
2	45	5.238		×			
3	45	5.548			×		
4	45	6.365				×	
5	45	9.070					×
Working pressure [MPa]							
0.20	54	6.768				×	
0.25	54	6.017			×		
0.30	54	5.683		×			
0.35	54	5.480	×				
0.40	54	5.491	×				

Szewczyk and Wilczok [2008], which showed that each boom deflection in a vertical plane leads to significant deterioration in the spaying quality, determined by the cross-distribution variability and coverage ratio. Increase in the liquid pressure from 0.20 to 0.30 MPa, every 0.05 MPa, created separate homogenous groups for the non-uniformity factor and was degressive within the range from 6.77 to 5.68%. Only the highest working pressure of 0.35 and 0.40 MPa created a single homogenous group with $CV =$ $= 5.48\%$. This is different when compared to the tests of single jet-steam sprayers, where a pressure difference by 0.05 MPa did not cause significant changes in the cross-distribution non-uniformity factor [Nowakowski 2007a].

TABLE 2. Analysis of significance of regression factors for the empirical model of cross-distribution non-uniformity for Twin flat nozzle

Independent variable	Regression factor	Mean error	t-Student	Significance level (P)
Constant	–35.19	7.85623	–4.48	<0.0001
h	139.06	32.0785	4.34	<0.0001
h^2	–125.99	32.0251	–3.93	0.0001
k	33.26	2.5924	12.83	<0.0001
p^{-1}	0.5282	$9.6007 \cdot 10^{-2}$	5.50	<0.0001
$h \times k$	–123.53	10.5952	–11.66	<0.0001
$h^2 \times k$	114.18	10.5776	10.79	<0.0001

The results of the tests performed point to significant differences in the cross-distribution non-uniformity factor for twin flat nozzle, depending on the height and angle of the boom and the liquid's working pressure. In the search for an overall explanation of the impact of the factors tested on changes in the non-uniformity factor and in order to be able to make forecasts, the elaboration of mathematical dependence became necessary. The test results obtained made it possible to search for multiple regression. The variables used in the model were assessed based on the t-Student value and significance level (Table 2), while the model as a whole was assessed based on the determination coefficient. Ultimately, an empirical model of the cross-distribution non-uniformity (CV) for twin flat nozzle was obtained, in the form of the following polynomial:

$$CV = -35.19 + 139.06\,h - 125.99\,h^2 + 33.26\,k + 0.5282\,p^{-1} - 123.53\,h\,k + 114.18\,h^2\,k \quad (1)$$

where:
CV – cross-distribution non-uniformity factor [%];
h – height of the boom [m];
k – angle of the boom [°];
p – working liquid pressure [MPa];

for which the determination coefficient equals 0.7567.

Therefore, it can be concluded that the mathematical model presented adequately describes changes in the cross-distribution non-uniformity factor for changed: boom height $h \in$ <0.4–0.6 m>, boom angle $k \in$ <0°–5°> and working liquid pressure $p \in$ <0.2–0.4 MPa>.

Based on the model proposed, it is possible to search for favourable conditions for the plant protection operation and predict the occurrence of unfavourable conditions. The most favourable configuration of the boom operation, i.e. the lowest values of the cross-distribution non-uniformity factor for twin flat nozzle, were recorded for a boom installed horizontally and operating within the height range of 0.4–0.5 m, with liquid pressure of 0.35–0.40 MPa (Fig. 1). The occurrence of strong boom deflections, 5° from the horizontal plane, with concurrent low location of the boom (ca. 0.4 m) and low working pressure of the liquid, shall produce the highest values of the cross-distribution non-uniformity factor. The comparison of the *CV* values obtained with the measurements and calculated in accordance with the model proposed is presented in Figure 2. The results of the statistical analysis confirm that the points describing the model adjustment to the measure-

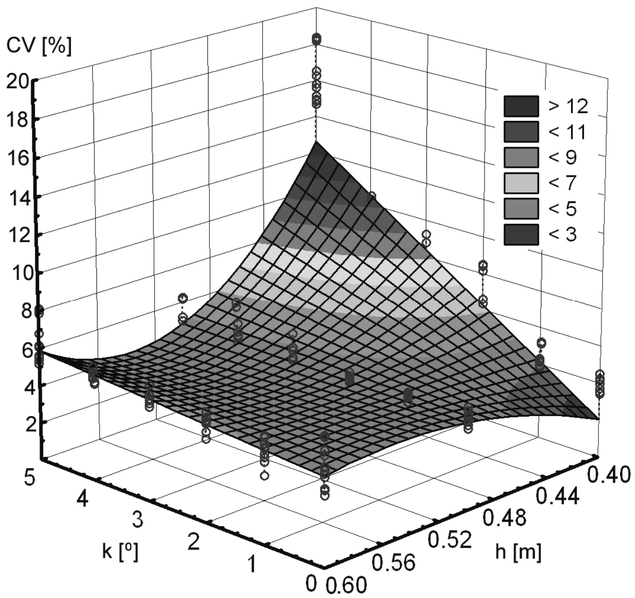

FIGURE 1. Impact of the angle (*k*) and height of the boom (*h*) on the cross-distribution non-uniformity (*CV*) factor for twin flat nozzle

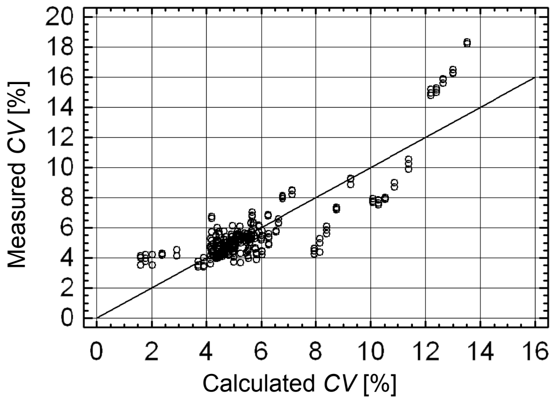

FIGURE 2. Comparison of measured and calculated values of the cross-distribution non-uniformity factor for twin flat nozzle

ment values are scattered, and point out to the model's defects. It is particularly visible for higher values of the cross-distribution non-uniformity factor, which correspond to low values of boom's height and large inclination angles.

CONCLUSIONS

1. Low values of the cross-distribution non-uniformity factor can be obtained through the appropriate selection and maintaining of the boom height above the sprayed surface as well as small boom inclination angle and working pressure 0.35–0.40 MPa.
2. The mathematical model elaborated can be used for control of the sprayer's operation in a manner allowing to obtain a low value of the cross-distribution non-uniformity factor.
3. Further works on the search for factors that have impact on the cross-distribution non-uniformity factor are necessary, to extend the model's adjustment to factual values.

REFERENCES

CZACZYK Z. 2012: Potencjał znoszenia cieczy wybranych rozpylaczy płaskostrumieniowych mierzony w tunelu aerodynamicznym. Journal of Research and Applications in Agricultural Engineering 57 (2): 41–46.

De SCHAMPHELEIRE M., NUYTTENS D., BAETENS K. 2009: Effects on pesticide spray drift of the physicochemical properties of the spray liquid. Precision Agriculture 10: 409–420.

DORR G.J., HEWITT A.J., ADKINS S.W., HANAN J., ZHANG H., NOLLER B. 2013: A comparison of initial spray characteristics produced by agricultural nozzles. Crop Protection 53: 109–117.

FERGUSON J.C., CHECHETTO R.G., O'DONNELL C.C., DORR G.J., MOORE J.H., BAKER G.J., POWIS K.J., HEWITT A.J. 2016: Determining the drift potential of Venturi nozzles compared with standard nozzles across three insecticide spray solutions in a wind tunnel. Pest Management Science doi: 10.1002/ps.4214.

HOŁOWNICKI R., DORUCHOWSKI G. 2006a: Rola techniki opryskiwania w ogranicza-

niu skażenia środowiska środkami ochrony roślin. Inżynieria Rolnicza 5(80): 239–247.
HOŁOWNICKI R., DORUCHOWSKI G. 2006b: Strefy ochronne o zróżnicowanej szerokości są konieczne. Mat. VI Konf. Racjonalna Technika Ochrony Roślin. Skierniewice: 90–100.
ISO 5682-3:1997. Equipment for crop protection – Spraying equipment – Part 3: Test methods for volume/hectare adjustment systems of agricultural hydraulic pressure sprayers.
KIERZEK R., WACHOWIAK M., KACZMAREK S., KRAWCZYK R. 2009: Wpływ techniki ochrony roślin na skuteczność wykonywanych zabiegów. Problemy Inżynierii Rolniczej 2: 75–81.
LODWIK D., PIETRZYK J. 2014: Ocena jakości pracy wybranych rozpylaczy płaskostrumieniowych w aspekcie poprzecznej nierównomierności oprysku. Motrol. Commission Of Motorization and Energetics in Agriculture 16 (1): 59–64.
MISZCZAK M. 2000: Elektroniczny stół rowkowy HARDI SPRAY SCANNER. Przegląd Techniki Rolniczej i Leśnej 1: 14–15.
NOWAKOWSKI T. 2004: Factor affecting the changes in coefficient of spray transverse distribution irregularity. Annals of Warsaw Agricultural University – SGGW, Agriculture (Agricultural Engineering) 45: 11–16.
NOWAKOWSKI T. 2005: Metody ograniczenia znoszenia cieczy podczas ochrony roślin. Technika Rolnicza Ogrodnicza Leśna 5: 14–16.
NOWAKOWSKI T. 2006a: Jak ograniczyć znoszenie cieczy? Nowe kierunki. Technika Rolnicza Ogrodnicza Leśna 7: 14–15.
NOWAKOWSKI T. 2006b: Model empiryczny współczynnika zmienności poprzecznej oprysku w zależności od parametrów technicznych opryskiwacza. Zeszyty Problemowe Postępów Nauk Rolniczych 508: 125–130.
NOWAKOWSKI T. 2007a: Selected technical parameters influencing the quality of spraying. Annals of Warsaw Agricultural University – SGGW, Agriculture (Agricultural Engineering) 50: 33–38.
NOWAKOWSKI T. 2007b: Współdziałanie wybranych parametrów oprysku na współczynnik zmienności rozkładu poprzecznego cieczy. Inżynieria Rolnicza 3 (91): 135–41.
NOWAKOWSKI T., OŚKO M. 2016: Influence of working parameters onto changes in the coefficient of non-uniform transverse liquid distribution. Annals of Warsaw University of Life Sciences – SGGW, Agriculture (Agricultural and Forest Engineering) 67: 41–48.
NUYTTENS D., BAETENS K., SCHAMPHELEIRE M., SONCK B. 2007: Effect of nozzle type, size and pressure on spray droplet characteristics. Biosystems Engineering 97: 333–345.
PARAFINIUK S., SAWA J., HUYGHEBAERT B. 2011: Ocena stanu technicznego belki polowej opryskiwacza metodą badania pojedynczych rozpylaczy. Inżynieria Rolnicza 5 (130): 207–214.
PARAFINIUK S., TARASIŃSKA J. 2013: Work simulation of the sprayer field beam with the use of R program. Journal of Central European Agriculture 14 (3): 166–175.
SZEWCZYK A., ŁUCZYCKA D. 2011: Ocena stopnia pokrycia opryskiwanych powierzchni asymetrycznym rozpylaczem dwustrumieniowym. Inżynieria Rolnicza 9 (134): 247–254.
SZEWCZYK A., ŁUCZYCKA D., LEJMAN K. 2011: Wpływ parametrów opryskiwania wybranym rozpylaczem dwustrumieniowym na stopień pokrycia opryskiwanych obiektów. Inżynieria Rolnicza 4 (129): 265–271.
SZEWCZYK A., WILCZOK G. 2008: Impact of the position of the sprayer field beam on the spatial distribution of the sprayed liquid and the degree of coverage of the treated surfaces. Eksploatacja i Niezawodność 1: 57–60.
ŚWIECHOWSKI W., HOŁOWNICKI R., GODYŃ A., DORUCHOWSKI G. 2013: Wpływ wysokości belki polowej i ciśnienia cieczy użytkowej na znoszenie sedymentacyjne. Inżynieria Rolnicza 3 (146): 389–397.
WANG S., DORR G.J, KHASHEHCHI M., HE X. 2015: Performance of Selected Agricultural Spray Nozzles using Particle Image Velocimetry. Journal of Agricultural Science and Technology 17: 601–613.

Streszczenie: *Model matematyczny współczynnika nierównomierności rozkładu poprzecznego cieczy dla rozpylaczy dwustrumieniowych.* W pracy przedstawiono analizę wyników badań współczynnika nierównomierności rozkładu poprzecznego cieczy dla rozpylaczy dwustrumieniowych. Na podstawie wyników opracowano model matematyczny współczynnika dla rozpylaczy dwustrumieniowych w zależności od wysokość i kąta ustawienia belki polowej oraz ciśnienia roboczego cieczy. Opracowany model umożliwia ocenę interakcji występujących między badanymi czynnikami i ich wpływu na współczynnik nierównomierności rozkładu poprzecznego cieczy.

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