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Received: 2016-08-29 ; Accepted: 2017-02-28

LABORATORY TEST OF THE NEW SPRAY DOSE ADJUSTMENT SYSTEM FOR FIELD SPRAYERS

Summary

The article presents an initial assessment of the new regulatory system of a spray dose adjustment system for field sprayers. In contrast to traditional sprayers, the proposed solution incorporates triple interlocked with diversified liquid expense nozzles controlled based on the dose adjustment process utilizing the forward and angular velocities of the machine. The adjustment system was tested using data gathered from monitoring the movement of a sprayer performing chemical plant preservation. The results prove that the system enables a substantial improvement in the surface distribution of the spray dose. Compared to the aforementioned traditional sprayer, where only 57.2% of measuring points have shown the spray dose being within 80-120% of nominal range, using the proposed solution the proper dose constituted 93.6% of all results.
***Key words**: field sprayer, dose adjustment, momentary dose, forward velocity, angular velocity*

BADANIA LABORATORYJNE NOWEGO SYSTEMU REGULACJI DAWKI CIECZY APLIKOWANEJ PRZEZ OPRYSKIWACZ POLOWY

Streszczenie

W artykule przedstawiono wstępną ocenę nowego systemu regulacji dawki cieczy aplikowanej przez opryskiwacz polowy. W porównaniu z tradycyjnym opryskiwaczem, w prezentowanym rozwiązaniu zamiast pojedynczych rozpylaczy zastosowano zblokowane rozpylacze trójelementowe o zróżnicowanym wydatku cieczy, sterowane w oparciu o proces regulacji dawki wykorzystujący wyniki dotyczące prędkości postępowej i kątowej maszyny. System regulacji przetestowano wykorzystując dane zebrane podczas monitorowania ruchu opryskiwacza realizującego chemiczną ochronę roślin. Uzyskane wyniki dowodzą, że system umożliwia znaczną poprawę rozkładu powierzchniowego dawki cieczy. W porównaniu z pracą monitorowanego na polu opryskiwacza, gdzie jedynie 57,2% punktów pomiarowych wykazywało dawkę cieczy należącą do zakresu 80-120% dawki nominalnej, przy użyciu proponowanego rozwiązania właściwa dawka cieczy stanowiła 93,6% wszystkich wyników.
***Słowa kluczowe**: opryskiwacz polowy, regulacja dawki, dawka chwilowa, prędkość postępowa, prędkość kątowa.*

1. Introduction

Chemical pesticides are an important factor in the process of increasing the yield and quality of agricultural output. The European Union's "sustainable use of pesticides" strategy should lead to the elimination of threats associated with their use [10]. The main environmental threat in agriculture is local contamination appearing in places where the pesticides accumulate [2]. Pesticides, while biologically affecting pests and crops, are not inert regarding humans and other flora and fauna in the ecosystem [6]. During field work, it is advised to perform chemical plant preservation tasks along straight lines and with a constant sprayer speed. In practice, there are conditions causing cultivators to change directions during the task [1]. Chemical preservation tasks are usually performed using tramlines. Those should be placed precisely in order to minimize the area with double spray coverage or no spray at all. The best results can be achieved while using automated driving systems as well [6]. Numerous authors [1, 8, 9] point out that the sprayer bar's horizontal movement can greatly influence the quality of the spray. This observation allows us to improve the solutions used to stabilize the horizontal fluctuations of the bar, unjustly neglected until now On the basis of monitoring the work of the sprayer performing the chemical plant preservation tasks on the area of 15.2 hectares, it was found that as a result of changes in speed and direction of movement, as much as 30.9% of the area was covered with a dose of liquid deviating from the nominal dose by more than 15%. There was also urgent need of the instigate of the research and implementation of solutions improving the operating parameters of field sprayer [3]. In order to keep the amount of liquid at acceptable levels in a wide range of speed and direction of movement of the sprayer, a new regulatory system has been developed at the West Pomeranian University of Technology in Szczecin [4].

2. The aim of the study

The objective of the research is to evaluate the developed spray dose adjustment system applied by a field sprayer moving with variable forward and angular velocity. In order to complete the aforementioned objective, the following questions have been formulated:
1. What are the momentary spray doses estimated using predictive simulation methods based on monitoring a field sprayer's work data and the performed adjustments?
2. What is the outcome from verifying the doses calculated using predictive simulation methods by comparing them with doses obtained during laboratory research using weight methods?

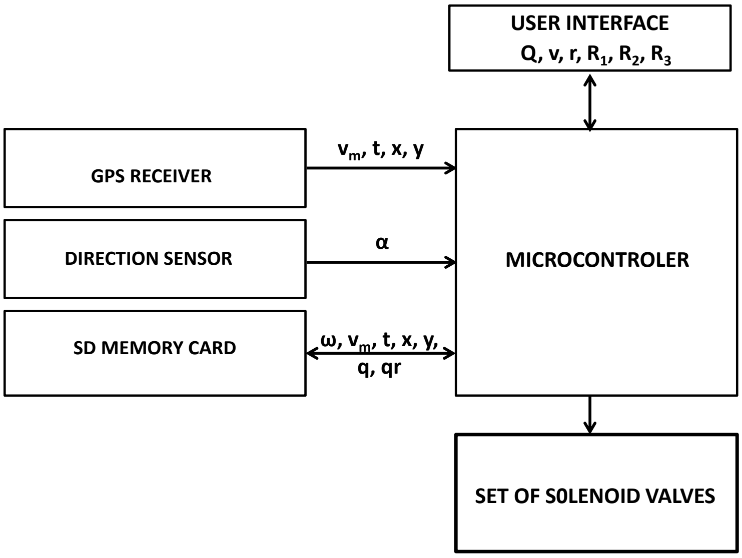

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Fig. 1. Block diagram of the spray dose adjustment system applied by individual nozzles
Rys. 1. Schemat blokowy układu regulacji dawki aplikowanej przez poszczególne rozpylacze

3. Materials and methods

The block diagram of the spray dose adjustment system is shown on fig. 1.

The system consists of a GPS receiver, direction sensor, microcontroller, user interface and a set of solenoid valves [4]. The GPS receiver transmits a $GPRMC sequence from which retrieves the current coordinate related to velocity and time data. The speed, time and angle of rotation of the sprayer measured by the transducer of the direction of movement are the variables needed to calculate the momentary liquid dose applied by the primary set of nozzles. The data related to the coordinates is not needed to realization the regulation. In the case of archiving performed treatments they fulfill an auxiliary function, and in this study, it makes possible to compile the drawings of the surface distribution of the spray doses. Contrary to sprayers used today, each nozzle is replaced with three, of different capacity (fig. 2).

This solution allows to achieve a total of 8 different spray doses. One of the doses is used as a nominal value (*Q*), whereas the remainder can be used to compensate for suboptimal forward or angular velocities, which results in exceeding the allowed dose, accepted as 80-120 [% *Q*] in this paper.

The following relationship is used to calculate the dose (1):

$$q = \frac{Q \cdot v}{v_m + \frac{\alpha \cdot r}{t}} = \frac{Q \cdot v}{v_m + \omega \cdot r} \ [\mathrm{dm^3 \cdot ha^{-1}}], \qquad (1)$$

where:
q – spray dose applied by the primary nozzle set [$\mathrm{dm^3 \cdot ha^{-1}}$],
Q – nominal dose [$\mathrm{dm^3 \cdot ha^{-1}}$],
v – nominal sprayer velocity accepted for the calculation [$\mathrm{m \cdot s^{-1}}$],
v_m – real forward velocity of the sprayer [$\mathrm{m \cdot s^{-1}}$] at time t,
α – angel of direction of sprayer [rad] at time t,
r – coordinates of sprayer position on working boom [m],
t - time between consecutive sequences $GPRMC [s].
ω – angular velocity of the sprayer [$\mathrm{rad \cdot s^{-1}}$] at time t.

The system consists of a GPS receiver, direction sensor, microcontroller, SD memory card, user interface and a set of solenoid valves [4]. The GPS receiver transmits a $GPRMC sequence to the controller, containing data about current coordinates, velocity and time. These data, along with the angular vector of movement, are used to calculate the dose applied through the primary set of nozzles. Contrary to sprayers used today, each nozzle is replaced with three, of different capacity (fig. 2). This solution allows to achieve a total of 8 different spray doses. One of the doses is used as a nominal value (*Q*), whereas the remainder can be used to compensate for suboptimal forward or angular velocities, which results in exceeding the allowed dose, accepted as 80-120 [% *Q*] in this paper.

The values of the parameters in the numerator (1) are entered to the microcontroller's memory by the user and are not changed during the spraying task.

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Fig. 2. Head equipped with three solenoid valve-controlled nozzles
Rys. 2. Głowica wyposażona w trzy rozpylacze sterowane za pomocą elektrozaworów

The variables v_m and α, located in the denominator, can change dynamically because of varied velocity and movement angle caused by the field layout and encountering obstacles, such as masts, trees or ponds, as well as caused by insufficient training of the machine operator.

It has been assumed that the turning angle of the sprayer to the left is positive and to the right - negative. Looking along the sprayer's direction of movement, coordinates of the nozzle located on the longitudinal turning axis have a null value, nozzles on the right of the axis have progressively positive values expressed in meters. The coordinates of the nozzles on the left of the axis have negative values. If the value calculated for the primary nozzles is not consistent with the acceptable range of values, the microcontroller finds and activates the proper combination of nozzles through the solenoid valves. Table 1 shows the basic data and combinations of used nozzles.

The baseline nozzle set in this research was combination no. 7, consisting of nozzles R_2 and R_3 for a total expenditure of 1.38 [$dm^3 \cdot min^{-1}$] and the nominal dose Q=237 [$dm^3 \cdot ha^{-1}$], for speed v-1.94 [$m \cdot s^{-1}$] and an internal pressure of 0.3 [MPa]. This set was being activated by the microcontroller if the calculated dose q was within 80-120 [%] of the nominal dose Q, or between 190 and 283 [$dm^3 \cdot ha^{-1}$]. If the calculated dose q had a value between 280-424 [%Q] for example, or 664-1004 [$dm^3 \cdot ha^{-1}$], set no. 2 was activated, which would change the calculated dose accordingly to the correction coefficient, or times 0.283, and because of that the momentary spray dose would still fit between 80-120 [%Q]. The adjustment properties for the nozzle sets can be shown as a graph of the relationship of the adjusted dose value q_r to the calculated value q (fig. 3). The graph shows that all calculated doses q with values between 62-428 [%Q] fall within the 80-120 [%Q] range. Doses higher than 0 but lower than 62 [%Q] are increased times 1.283, but do not reach the minimal correct value of 80 [%Q]. If the calculated dose q is higher than 424 [%Q], or exceeds the nominal dose Q set by the user four times, it has been agreed that the correct decision is to disable the nozzles. The same reaction takes place for q<0 [%Q], or doubled spray coverage. Simulations have been carried out in order to test the adjustment system. During the tests, monitoring movement data from a sprayer performing chemical preservation tasks was used. The selected task fragment is approximately 180 [m] long, with noticeable velocity and direction changes (fig. 4). Using the data saved on the SD card concerning time, forward and angular velocity of the sprayer, as well as the nominal dose and the speed set for the spraying task, the microcontroller calculated the momentary dose q and qr for nozzles with coordinates r and subsequently activated the different combinations of nozzles. Dose data q and qr were saved on the SD card and later used to prepare charts showing the area distribution, as well as a momentary dose histogram.

Table 1. Basic data for nozzles R_1, R_2, R_3 and their combinations (No.) [7]
Tab. 1. Podstawowe dane rozpylaczy R_1, R_2, R_3 oraz ich kombinacji (No.) [7]

No.	Expenditure for press. 0.3MPa				Q for v=1.94$m \cdot s^{-1}$	Calculated dose q		Correction coefficient	Adjusted dose qr	
	$dm^3 \cdot min^{-1}$				$dm^3 \cdot ha^{-1}$	$dm^3 \cdot ha^{-1}$	%Q		$dm^3 \cdot ha^{-1}$	%Q
	R_1	R_2	R_3	$R_1+R_2+R_3$						
1.				0	0	>1004	>424	0.000	0	0
2.	0.39			0.39	67	664-1004	280-424	0.283	188-284	80-120
3.		0.59		0.59	101	495-664	209-280	0.428	212-284	89-120
4.			0.79	0.79	135	399-399	168-209	0.572	228-283	96-120
5.	0.39	0.59		0.98	168	331-399	140-168	0.710	235-283	99-119
6.	0.39		0.79	1.18	202	283-331	120-140	0.855	242-283	103-120
7.		0.59	0.79	1.38	**237**	190-283	80-120	1.000	190-283	80-120
8.	0.39	0.59	0.79	1.77	303	0-190	0-80	1.283	0-244	0-103

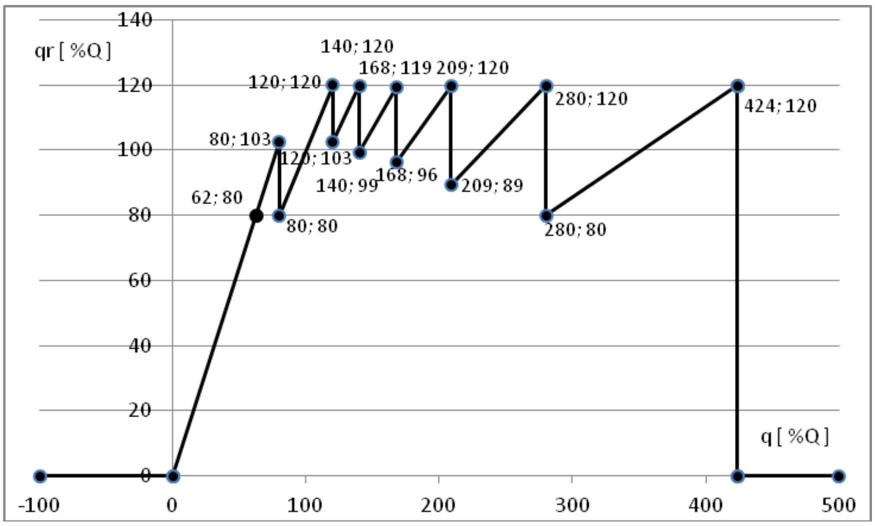

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Fig. 3. The relationship between dose qr after adjustment and the calculated dose
Rys. 3. Zależność dawki qr po regulacji od dawki obliczonej q

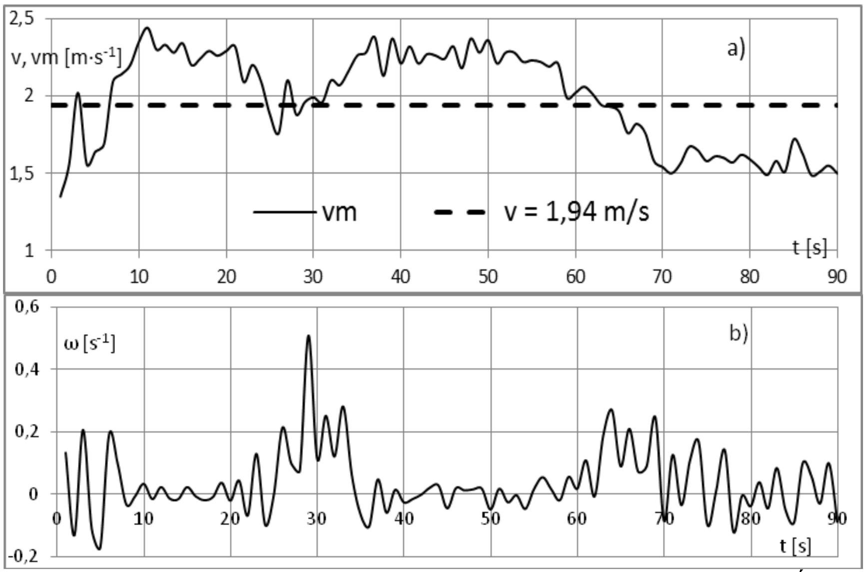

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Fig. 4. Monitoring values used: forward velocity (v_m) and angular velocity (ω) of a sprayer with an operating width of b=20 [m], Q =234 [dm^3·ha^{-1}], v=1.94 [m·s^{-1}], p=0.4 [MPa], nozzles TT11003 [7]

Rys. 4. Wykorzystane wyniki monitorowania prędkości postępowej (v_m) i kątowej (ω) opryskiwacza o szerokości roboczej b=20 [m], Q =234 [dm^3·ha^{-1}], v=1,94 [m·s^{-1}], p=0,4 [MPa], rozpylacze TT11003 [7]

In order to verify the results regarding the momentary dose *qr*, a laboratory measurement of the real amount of liquid sprayed by the nozzle sets has been carried out. Liquid volume changes during a 90 [s] adjustment cycle were performed for nozzles located the furthest from the axis of the sprayer: r =-9.75 and r = 9.75 [m]. A laboratory scale with a vessel for the liquid was used. The measurements of the scale were recorded by a PC with a frequency of 5 Hz. The acquired results of momentary nozzle spray amounts and data regarding velocity *vm*, operating width of the nozzle sets and time *t*, were the basis for calculating the adjusted doses (*qrw*).

In order to test if the doses calculated with simulation methods (*qr*) correspond to the values acquired with weight methods (qrw), the linear correlation coefficient *R* and the quotient of average values of both doses *Dq* were used. The verification is positive if the correlation coefficient value is not less than 0.98 and the quotient of average values is within 0.95-1.05 [5].

Values of the linear correlation coefficient *R* were calculated using the relationship below:

$$R = \frac{\sum_{i=1}^{n}(qr_i - \overline{qr})\cdot(qrw_i - \overline{qrw})}{\sqrt{\sum_{i=1}^{n}(qr_i - \overline{qr})^2 \cdot \sum_{i=1}^{n}(qrw_i - \overline{qrw})^2}}, \qquad (2)$$

The quotient *Dq* was calculated based on the average doses *qr* and *qrw*:

$$Dq = \frac{\overline{qr}}{\overline{qrw}}. \qquad (3)$$

4. Results

In order to facilitate interpretation, all results in the later parts of the article regarding the monitoring dose *q* [dm^3·ha^{-1}], as well as the adjusted dose *qr* or *qrw* [dm^3·ha^{-1}], will be presented as a percentage of the adjustment dose *Q*, measuring 237 [dm^3·ha^{-1}]. Results concerning the momentary spray values have been shown on fig. 5. All data shown were acquired via simulation based on the results from monitoring the sprayer's field route (fig. 5a) and the dose adjustment (fig. 5b). Momentary spray values *q* acquired based on monitoring are varied to a high degree along the entire route. Major deviations from the nominal dose *Q* appear not only during change of direction, but on straight lines as well, if the momentary velocity was different than nominal and was changing often. Talking with the operator about field driving techniques has shown that the main cause of errors lies in the necessity of keeping close to the route while avoiding various field obstacles.

Highly beneficial results have been observed when using the adjustments. Momentary doses on the turns and straights have shown improvements. Spray doses *qr* over the entire route did not exceed 120 [%*Q*]. Doses smaller than 80 [%*Q*] were rarely observed around the outsides of turns, where the monitored doses had values smaller than 62 [%*Q*]. During the adjustment, doses were multiplied times 1.283 but their final values did not reach the acceptable bottom line (80-120 [%*Q*]). It is worth noting that despite large adjustment possibilities, the operator should not allow for the dose to rise above the 62-424 [%*Q*] range.

Fig. 6 shows the histogram of measuring points before and after adjustment. The graph was prepared based on data from 2 x 3600 measuring points. The intervals correspond to the adjustment ranges, the 0-62 [%*Q*] range was divided into two parts: 0-50 and 50-62 [%*Q*]. Before the adjustment, 57.2% of all measuring points were showing dose *q* within the acceptable range of 80-120 [%*Q*]. 7.9% of measuring points were in the 120-140 [%*Q*] range. The ranges with increasing doses had less points each. The range of 424 [%*Q*] or more had only 2% of measuring points. A fairly large number of points appeared with a dose less than 80 [%*Q*]. The definitive cause of this consisted in excessive forward velocity of the sprayer. As much as 15% of doses were in the 62-80 [%*Q*] range. Less-than-zero values, meaning doubled spray, were 1.2 [%] of all doses. After performing the adjustment, the amount of doses in the 80-120 [%*Q*] range increased noticeably and was at 93.6 [%]. This range now contained all of the doses showing values between 62-424 [%*Q*] before. The adjustment caused 3.2 [%] of doses to zero completely – these were the doses with values lower than 0 [%*Q*] or higher than 424 [%*Q*].

Fig. 7 shows the data gathered in order to verify the simulation research by comparing with the results acquired with the weight method. These data apply to the dynamics of dose changes in the points furthest away from the sprayer's turning axis. The momentary dose will have the most difference from nominal *Q* values there. Both charts contain two straight, horizontal lines outlining the 80-120 [%*Q*] dose value range. The green curves present the adjusted dose *qr* calculated by the microcontroller based on simulations for nozzles with coordinates between r=-9.75 and r=9.75 [m]. Red curves present dose *qrw* after adjustments and the values used to plot them were estimated based on measuring the continuous liquid expenditure applied by nozzle sets.

The carried out result verification proves that there are no differences between dose *qrw* amounts estimated using the weight scale and the *qr* dose calculation results saved on the SD card by the microcontroller. For nozzles placed at r=-9.75 and r=9.75 [m], the linear correlation coefficient *R* values were respectively 0.995 and 0.992, whereas *Dq* quotient values were 0.994 and 1.006.

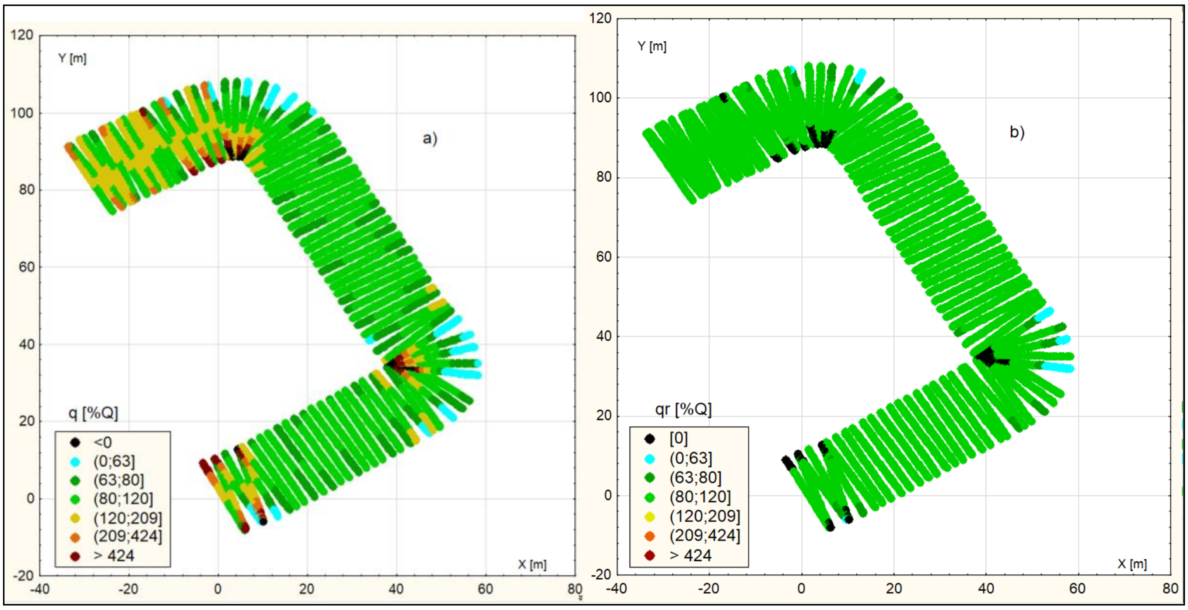

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Fig. 5. Surface distribution of momentary spray doses: a) monitoring results, b) adjustment results
Rys. 5. Rozkład powierzchniowy chwilowych dawek oprysku: a) wyniki monitoringu, b) wyniki regulacji

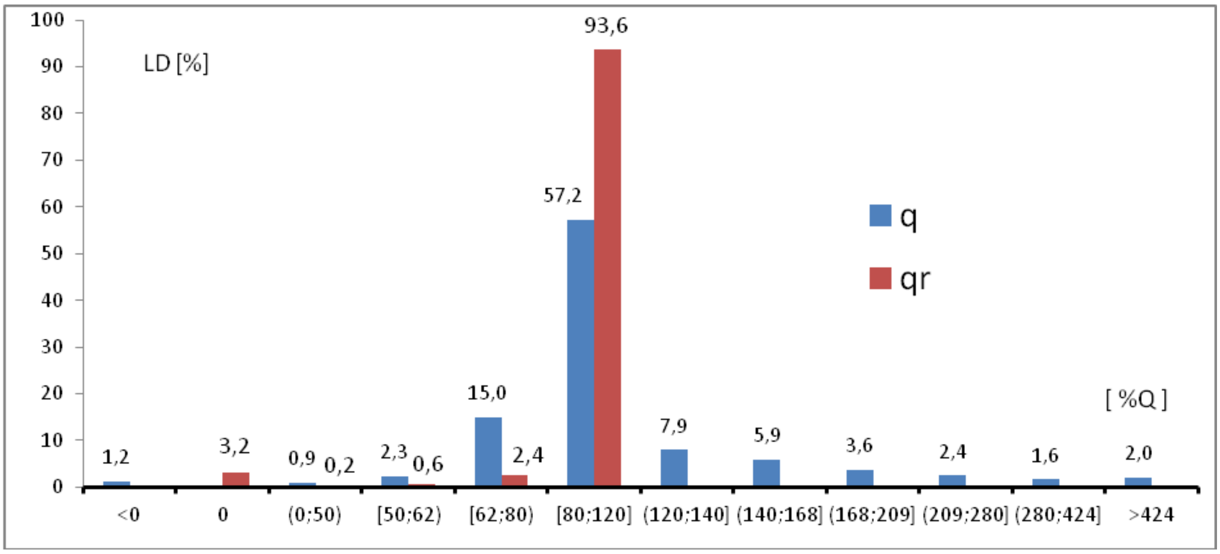

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Fig. 6. Dose quantity (LD) histogram: q – monitoring results, qr – adjustment results
Rys. 6. Histogram liczebności dawek (LD): q –wyniki monitoringu, qr – wyniki regulacji

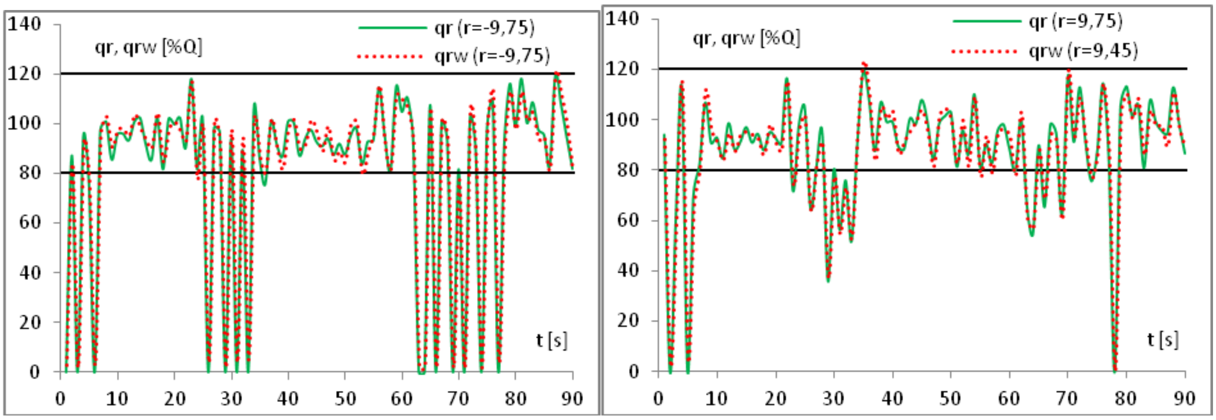

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Fig. 7. Dose change dynamics after adjustment calculated based on simulations (*qr*) and dose estimated using the weight method (*qrw*) for edge nozzles with coordinates of r =-9.75 and r = 9.75 [m]

Rys. 7. Dynamika zmian dawki po regulacji obliczonej na podstawie symulacji prognostycznej (qr) oraz dawki oszacowanej metodą wagową (qrw) dla skrajnych rozpylaczy o współrzędnych; r = -9,75; r = 9,75 [m]

5. Conclusions

1. The research shows that the described concept of a dose adjustment system for use in field in field spraying is correct.
2. The described system properly adjusts all doses with values falling into the range of 62-424% of nominal dose.
3. The adjustments carried out on the monitored route of the field sprayer raised the percentage of doses with values within 80-120% of nominal from 57.3 to 93.6%.
4. No discrepancies between the regulated dose values found in simulations and weight methods.
5. Further research on the proposed adjustment system is advised.

6. References

[1] Anthonis J., Audenaert J., Ramon H.: Design Optimisation for the Vertical Suspension of a Crop Sprayer Boom, Biosystems Engineering, 2005, 90(2), 153-160.
[2] Doruchowski G., Hołownicki R.: Przyczyny i zapobieganie skażeniom wód i gleby wynikających ze stosowania środków ochrony roślin. Zeszyty IMUZ, 2003, 9, 96-115.
[3] Garbiak K., Jurga J.: The prognostic simulation of momentary dose of liquid applied by field sprayer without an automatic pressure control. Journal of Research and Applications in Agricultural Engineering, 2015, 60 (1), 5-10.
[4] Garbiak K., Jurga J.: Sposób regulacji dawki cieczy w opryskiwaczach polowych podczas zmiany kierunku ruchu oraz opryskiwacz. Zgłoszenie wynalazku P. 407372. Biuletyn Urzędu Patentowego, Warszawa, 2015, 19(1088), Rok XLIII, 2.
[5] Gawęcki J., Wagner W.: Podstawy doświadczalnictwa w nauce o żywieniu i żywności. AR, Poznań, 1988.
[6] Hołownicki R., Doruchowski G., Godyń A., Świechowski W.: Technika ochrony roślin w dyrektywach UE. Inżynieria Rolnicza, 2011, 4(129), 74-84.
[7] Katalog produktów TeeJet Technologies. 2011. 51-PL.
[8] Lardoux Y., Sinfort C., Enfalt P., Miralles A., Sevila F.: Test Method for Boom Suspension Influence on Spray Distribution, Part II: Validation and Use of a Spray Distribution Model. Biosystems Engineering, 2007, 96(2), 161-168.
[9] Lardoux Y., Sinfort C., Enfalt P., Sevila F.: Test Method for Boom Suspension Influence on Spray Distribution, Part I: Experimental Study of Pesticide Application under a Moving Boom. Biosystems Engineering, 2007, 96(1), 29-39.
[10] Makles Z., Domański W.: Ślady pestycydów – niebezpieczne dla człowieka i środowiska. Bezpieczeństwo Pracy, 2008, I, 5-9.