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Investigation of an automatic pesticide rate control system for a self-propelled boom sprayer

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Abstract

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A one-year field experiment was conducted in the land of the town of Merichleri, Central Bulgaria (42°08′37′′N 25°29′56′′E), to investigate a self-propelled boom sprayer with automatic control for the consumption rate according to the parameter Deviation from the consumption rate (DCR). The study presents small-volume spraying at a fixed consumption rate of 150 l/ha in three operating modes of a self-propelled sprayer (Working mode 1 (WM1) – 10km/h, Working mode 2 (WM2) – 13 km/h and Working mode 3 (WM3) – 15 km/h). With a soil moisture meter AM-128 SOIL, the instantaneous soil moisture in the studied area was measured to establish its influence on the operation of the sprinkler. The applied Univariate ANOVA analysis shows the presence of significant differences at $p < 0.05$ between the selected operating modes of the sprayer. Correlation analysis revealed a downward, weak to moderate relationship (-0.227; -0.410; -0.412) between sprinkler working speed (SWS) and soil moisture (SM) for the three operating modes. A weak to moderate but positive correlation (0.069; 0.243; 0.488) is also observed between SM and deviations from the consumption rate, indicating that as SM increases, so does the consumption rate. The strongest, negative correlation was found between SWS and DCR (-0.783; -0.953; -0.977), i.e. as SWS increases, DCR decreases. Two types of regression models (Linear and Cubic) were compared at $p < 0.05$ defining the relationship between SWS and DCR in the three operating modes. The cubic model in WM2 is characterized by the best estimation error, high coefficient of determination ($R^2 = 0.937$) and best describes the studied parameters.

Keywords: plant protection machines; consumption rate; setting up a self-propelled boom sprayer; statistical analysis

Introduction

The enemies of cultural plants annually destroy not a small part of the world's agricultural production (Revyakin & Krakhovetsky, 2010; Prakash et al., 2021). In some countries, in certain years, the destruction of the entire production has been observed (Guest, 2017). Therefore, as paradoxical as it may sound, we humans only harvest the produce that our plant enemies have left us. Three types of enemies are observed on cultivated plants – weeds, diseases and pests. The fight against them is carried out through a specialized plant protection technique, which has undergone great development in recent years (Xiongkui, 2019; Kruk et al., 2015; Starostin & Eshchin, 2021). The use of innovative technologies leads to new changes in the agricultural production (Ahmad, 2021). The development of new automated machinery for crop protection activities helps competitiveness and sustainability in agriculture with a positive impact on the quality of production (Calegari et al., 2013). Effective use of plant protection machinery plays an important role in disease, pest and weed control by properly dosing, spreading and distributing the recommended doses of chemicals on the intended target (Trifonov & Zyapkov, 2000; Trifonov & Zyapkov, 2010; Dou et al., 2018; Prakash et al., 2021). Farmers can customize crop protection machinery to form a system that meets their unique needs and management style (Batte & Ehsani, 2006).

In recent years, automatic control systems for plant protection machines have been an important element of precision agriculture worldwide (Utkov et al., 2015; Iliev, 2016; Zhang et al., 2018). Such systems are available from many manufacturers and are suitable for installation on self-propelled, trailed and mounted sprayers. Through the systems of automatic control of the sprayer sections, farmers aim to reduce the total costs of plant protection of the crops and the overlapping of spraying, which is carried out by the automatic shutdown of the corresponding section when passing over an already sprayed surface of the crop. The precise operation of these systems is ensured by using maps on which the borders of the field are set in advance or those drawn by the driver in a preliminary move along the working trajectory of the machine (Luck et al., 2010; Iliev, 2016).

Automatic section control maintains a preset flow rate by controlling the flow rate of liquid supplied to the sections. Flow rate controllers compensate for changes in sprinkler operating speed by varying pump flow rate based on flow meter and operating speed sensor data. The flow meter provides data to check the automatic maintenance of the flow rate of the working fluid (Luck et al., 2011; Singh Makkar & Kumar Gangwar, 2022). An important component in automatic control systems is the GPS receiver, which provides coordinates for the controller (Iliev, 2016). Machine speed information provided by the GPS receiver, combined with information from nozzle flow control systems, can ensure the application of uniform surface doses of pesticides (Garcia-Ramos et al., 2011).

The goal of the present work is to investigate a self-propelled boom sprayer with automatic control for the consumption rate according to the parameter Deviation from the consumption rate.

Materials and Methods

Experimental design

The research was conducted in 2022 on the land situated near the town of Merichleri in the central part of the Republic of Bulgaria. Coordinates of the experimental field are 42°08′37″N 25°29′56″E (Figure 1). The object of the research is a self-propelled boom sprayer with a hydraulic boom length of 30 meters (Figure 2). The conducted experiment imitates small-volume spraying at a set consumption rate of 150 l/ha, at three operating speeds (10 km/h, 13 km/h and 15 km/h). The operating modes of the sprayer are indicated respectively:

- Working mode 1 (WM1) – the aggregate was set to the speed of 10 km/h and a consumption rate of 150 l/ha.
- Working mode 2 (WM2) – the aggregate was set to the speed of 13 km/h and a consumption rate of 150 l/ha.
- Working mode 3 (WM3) – the aggregate was set to the speed of 15 km/h and a consumption rate of 150 l/ha.

Soil moisture was measured at equal intervals of 2 m along the entire length of the experimental field at a depth of 15 cm with a soil moisture meter AM-128 SOIL. This has been done to track the effect of soil moisture on sprinkler performance.

Fig. 1. Experimental field (42°08′37″ N 25°29′56″ E)

Fig. 2. Hydraulic boom of the self-propelled sprayer

Programming the on-board computer for a given consumption rate

The programming of the on-board computer is done manually by entering the rates that will be worked with depending on the need (the quantity of the pesticide). Figure 3 shows the sequence for setting the parameters of the aggregate. For the specific study, the controller is programmed for a flow rate of 150 l/ha pesticide. The distance at which the spent amount of solution is measured is 33.3 m, which corresponds to 0.1 ha of cultivated area (according to the working width of the machine). The sprayer tank is filled with 1000 l of water. The computer of the aggregate is set for work and the studied section is passed in automatic mode, aiming to maintain the set speed of the unit. Spreaders suitable for the given conditions are selected and the machine is adjusted. The sprayer passes through the experimental field, after which the amount of solution remaining in the tank is read from the display. The tank is refilled with a solution until it reaches the 1000 l level. For each set speed of the aggregate (10 km/h, 13 km/h and 15 km/h) the test was performed with repeatability 10 times.

The deviation from the set consumption rate is calculated by the formula:

$$DCR = CR - (1000 - SC), \quad (1)$$

where: *DCR* is the Deviation from the consumption rate, l/ha;

CR – Consumption rate (150 l/ha);

SC – Solution consumption.

Statistical data analysis

The significant differences between the sprayer's working speeds, km/h (SWS) for the different working modes of the machine unit, and the differences between the deviations from the consumption rate, l/ha (DCR) are analyzed by Univariate ANOVA with Post Hoc Tukey test.

Correlation analysis is used to examine the strength and direction of the relationship between the sprayer's working speeds, consumption rate deviations, and the instantaneous soil moisture (SM), measured at the experimental field.

The influence of the sprayer's working speeds on the consumption rate deviations for the different working modes of the unit is studied by Regression analysis at $p < 0.05$. The main goal is to calculate predictive models defining the relations between examined parameters. Two regression models are compared – Linear (2) and Cubic (3), expressed with the formulas:

$$Y = const.x + b \quad (2)$$

$$Y = const. + b_1x + b_2x^2 + b_3x^3, \quad (3)$$

where: *Y* is the observed parameter Deviation from the consumption rate, l/ha of the solution at the different working modes of the unit;

x is the fixed factor Sprayer's working speed and *const.;* b_1; b_2; b_3 are the model coefficients.

The IBM® SPSS® Statistics 26.0 software was used to process the data.

Results and Discussion

The consumption rate deviation of pesticide is monitored when the sprayer moved at three different operating speeds (10 km/h, 13 km/h and 15 km/h) and regression models ex-

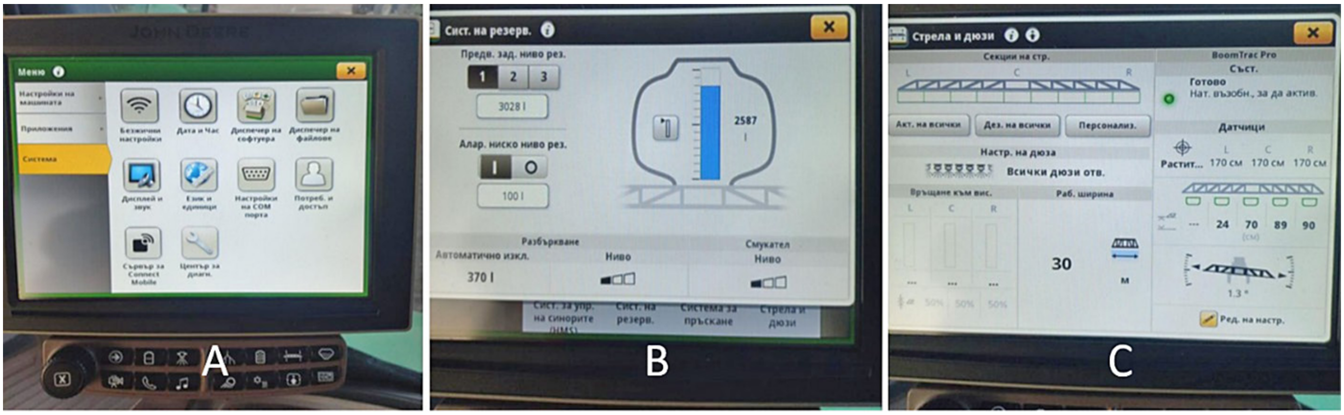

Fig. 3. Setting up of the aggregate parameters
***A* – Machine setup display, *B* – Display for reading the amount of pesticide in the tank, *C* – Adjusting the height of the hydraulic rod**

pressing the relationship between them are developed. The measured instantaneous soil moisture in the studied area varies from 38.6% to 43.2%, i.e. the average humidity for the entire studied area is 40.05%.

Univariate ANOVA and Correlation analysis

Table 1 presents the average values of the calculated parameters SWS and DCR for the three operating modes of the unit and for the recorded momentary soil moisture of the experimental field. Regarding the operating speed of the sprayer, the results of the applied Univariate ANOVA analysis show the presence of significant differences at $p < 0.05$ between the average speed of WM1 and the speeds of the other two operating modes, as well as between WM2 and WM3. From the calculated Coefficient of determination (0.982), it can be concluded that 98.2% of the variations in the aggregate's operating speed are due to the selected operating mode. As for the parameter Deviation from the consumption rate, significant differences between the average DCR values obtained for WM1 and WM3 operating modes are reported. No significant differences about this parameter between WM1 and WM2, and between WM2 and WM3 are reported. The low Coefficient of determination (0.148) indicates that only 14.8% of the variations in DCR are due to the different operating modes of the aggregate.

The correlations between the operating speed of the sprinkler, instantaneous soil moisture and deviation from the consumption rate for the three operating modes of the unit at the level of significance $p \leq 0.01$ are presented in Table 2. The results show that the relationship between sprayer operating speed and soil moisture is downward and ranges from weak to moderate (-0.227; – 0.410; – 0.412) for all three operating modes. The relationship between soil moisture and deviations from the cost norm also varies from weak to moderate (0.069; 0.243; 0.488) for the three operating regimes but is positive, i.e. with an increase of soil moisture, the deviations from the consumption rate also increase. On the other hand, the analysis shows that there is a strong, negative correlation between the speed of the machine unit and deviations from the consumption rate (- 0.783; – 0.953; – 0.977) for all three studied working modes. The negative relationship is an indicator that as the working speed of the aggregate increases, the deviation from the consumption rate decreases. The strong correlation justifies the creation of various regression models and the analysis of the influence of the operating speed of the unit on deviations from the consumption rate.

Regression models

The calculated regression models expressing the influence of the working speed on the parameter Deviation from the consumption rate in the three different working modes of the self-propelled sprayer are presented in Table 3 and Figure 4a-c. As can be seen from the table, both linear and non-linear regression models for the three operating modes are statistically significant at $p < 0.05$. The values of the coefficients of determination of the Linear and Cubic models at

Table 1. Basic statistics and Univariate ANOVA of the observed parameters Sprayer's working speed and Deviation from the consumption rate for the different working modes of the aggregate

Working mode (n = 30)	Sprayer's working speed, km/h			Deviation from the consumption rate, l/ha		
	$\bar{x}$±SD	Sig. (p)	R^2	$\bar{x}$±SD	Sig. (p)	R^2
WM1	9.93±0.133 [a]	0.0049	0.982	-0.110±1.226 [a]	0.0116	0.148
WM2	12.94±0.346 [ab]			-0.195±1.138		
WM3	15.17±0.386 [ab]			-0.207±0.890 [a]		

*Same superscripts within the same column represent significant differences at the level of significance $p < 0.05$ as follows: [a-a] between WM1 and all other working modes; [b-b] between WM2 and all other working modes; Post Hoc test: Tukey; SD – Standard deviation; R^2 – Coefficient of determination; n – number of the observations

Table 2. Crosstab correlation between examined parameters Sprayer's working speed, Soil moisture, and Deviation from the consumption rate for the different working modes of the aggregate

n = 30	WM1 (10 km/h)			WM2 (13 km/h)			WM3 (15 km/h)		
	SWS	SM	DCR	SWS	SM	DCR	SWS	SM	DCR
SWS	1	- 0.410	- 0.783*	1	- 0.412	- 0.953*	1	- 0.227	- 0.977*
SM	–	1	0.243	–	1	0.488	–	1	0.069
DCR	–	–	1	–	–	1	–	–	1

*Correlation is significant at $p < 0.01$

Legend: SWS – Sprayer's working speed (km/h); SM – Soil moisture (%); DCR – Deviation from the consumption rate (l/ha); WM1, WM2, and WM3 – Sprayer's working modes

Table 3. Models' summary and models' coefficients estimation, expressing the relation between the parameter Deviation from the consumption rate from the Sprayer's working speed at investigated working modes of the aggregate

Parameter estimates	Equations	Std. Error of the Estimate	Sig.	R^2
Working mode 1				
Linear	$DCR = -4.069x + 39.212$	0.8087	0.007	0.613
Cubic	$DCR = -55.779+10.236x - 0.048x^3$	0.7961	0.035	0.615
Working mode 2				
Linear	$DCR = -3.273x + 40.351$	0.3655	0.001	0.908
Cubic	$DCR = -105.402 + 13.744x - 0.034x^3$	0.3265	0.001	0.937
Working mode 3				
Linear	$DCR = -3.493x + 50.223$	0.2021	0.000	0.954
Cubic	$DCR = 82.522 - 6.731x + 0.005x^3$	0.2012	0.000	0.954

*Level of significance $p < 0.05$

WM3 are the highest ($R^2 = 0.954$), i.e. about 95.4% of the variations in the deviation from the consumption rate can be explained by the influence of the sprayer's operating speed. Figure 4c shows the estimation of the curves of the developed regression models at WM3. As can be seen from the figure, the two models overlap almost completely. Although their coefficients of determination are the highest, the estimation errors are the lowest (0.2012; 0.2021) and the DCR is the smallest (-2.07; Table 1) it is impossible to determine which of the two models is more suitable for describing the studied parameters. As for the regression equations describing the other two working modes, WM2 is distinguished by higher coefficients of determination (0.908; 0.937) compared to WM1. Moreover, the estimation errors of the models are smaller compared to those of WM1 (Table 3), as well as the deviation from the consumption rate (-1.95; Table 1).

As can be seen from Figure 4a and Figure 4b, the calculated regression models at WM2 of the sprayer described the studied parameters better than the calculated models at WM1. Moreover, the Cubic model has a higher Coefficient of determination (0.937, Table 3) than the Linear one. The error of the Cubic model (0.3265) is lower than that of the Linear model (0.3655), which is a reason to conclude that the Cubic model at WM2 best describes the relationship between the sprayer's operating speed and the deviation from the consumption rate.

Conclusions

A self-propelled boom sprayer with automatic flow rate control was tested at three working modes: WM1 (10 km/h), WM2 (13 km/h), and WM3 (15 km/h) aggregate's speed and pesticide consumption rate – 150 l/ha.

Significant differences between the average speed of WM1 (9.93 km/h) and those of the other two operating modes, as well as between WM2 (12.94 km/h) and WM3 (15.17 km/h) were reported.

For the three operating modes of the sprinkler, the following deviations from the consumption rate were obtained: at WM1 -1.10 l/ha; at WM2 -1.95 l/ha, and at WM3 -2.07 l/ha, respectively. Significant differences between average values of the parameter DCR were reported mainly at WM1

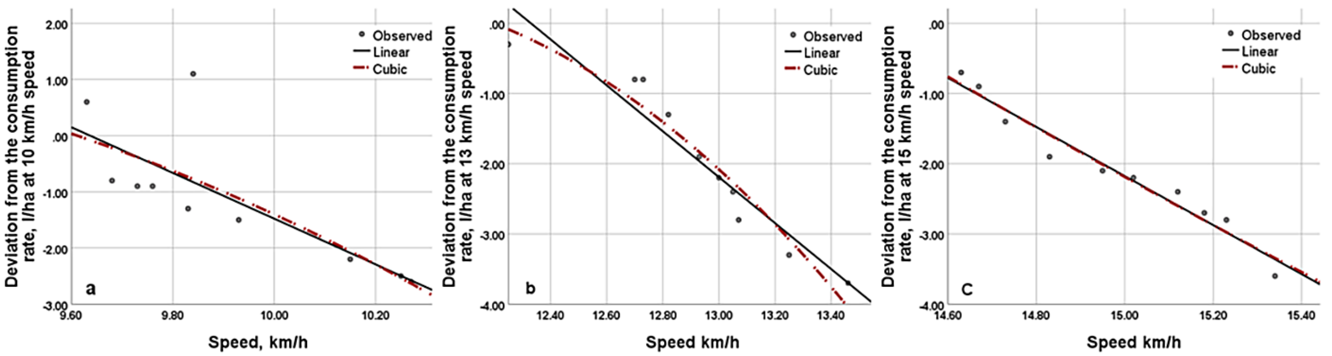

Fig. 4. Curves' estimation of the regression models showing the relation between the Deviation from the consumption rate and the Sprayer's working speeds

and WM3 of the sprinkler. No significant differences were reported between the deviations from the consumption rate at other operating modes.

A downward, weak to moderate correlation (-0.227; -0.410; -0.412) was found between sprayer's operating speed and soil moisture, as well as a weak to moderate but positive correlation (0.069; 0.243; 0.488) between soil moisture and deviations from the consumption rate for all three working modes. The strongest, negative correlation (-0.783; -0.953; -0.977) was recorded between the sprayer's operating speed and deviations from the consumption rate.

Two types of regression models (Linear and Cubic) were calculated, expressing the influence of the sprayer's operating speed on the parameter Deviation from the consumption rate in the three different working modes of the unit. Of all the compiled models, the Cubic model at WM2 is characterized by the best estimation error and a high coefficient of determination (R^2=0.937) and best describes the studied parameters.

The developed models could be used by farmers in optimizing the performance of automatic pesticide application management systems.

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