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THE EFFECT OF THE TYPE OF PREPARATION WITH THE CONTENT OF NANO-COPPER AND COPPER ON THE COVERAGE OF WINTER RAPE PLANTS

Summary

The aim of the study was to determine the average total coverage of winter rapeseed surface sprayed with copper foliar fertilizer and nano-copper and to determine the total plant surface in the three development stages studied (12, 14 and 16 BBCH). Coverage studies were carried out in the "Aporo1" chamber at a speed of 0.86 m·s^{-1}, pressure of 0.20 and 0.28 MPa, using two conventional nozzles for spraying: XR 110-02 and DF 120-02. To determine the size of the coverage, the samplers were used in the form of water-sensitive papers attached to the horizontal and vertical surfaces of artificial plants. The degree of coverage was determined by a computer method of image analysis. To determine the size of the projections of the horizontal and vertical surfaces of the studied plants, they were photographed in each development phase, then they were subject to graphic processing. In Scan2Cad, photos were transformed into a vector image, then using the AutoCad 2014 program, the projection size of the tested surfaces was read. The total surface of plants was determined after determining the size of vertical and horizontal projections of plants. It was found that after use of the DF 120-02 nozzle, a better coverage of the sprayed plants was achieved in each development phase and with all applied spraying parameters compared to the XR 110-02 nozzle. There was no statistically significant effect of the nano-element on the value of average coverage of the surface of the winter rapeseed plants.
***Key words**: degree of coverage, nano-copper, foliar fertilizer, spraying of plants, nozzle, plant morphology*

WPŁYW RODZAJU PREPARATU Z ZAWARTOŚCIĄ NANOMIEDZI I MIEDZI NA POKRYCIE ROŚLIN RZEPAKU OZIMEGO

Streszczenie

Celem badań było określenie średniego całkowitego pokrycia powierzchni rzepaku ozimego opryskiwanego nawozem dolistnym miedzi i nanomiedzią oraz wyznaczenie powierzchni całkowitej roślin w trzech badanych fazach rozwojowych (12, 14 i 16 BBCH). Badania stopnia pokrycia przeprowadzono w komorze "Aporo1" przy prędkości 0.86 m·s^{-1}, ciśnieniu 0.20 oraz 0.28 MPa, wykorzystując do oprysku dwa rozpylacze standardowe: XR 110-02 oraz DF 120-02. Aby wyznaczyć stopień pokrycia zastosowano próbniki w postaci papierków wodoczułych przyczepianych do poziomych i pionowych powierzchni sztucznych roślin. Stopień pokrycia wyznaczono komputerową metodą analizy obrazu. Aby określić wielkość rzutów powierzchni poziomych i pionowych badanych roślin wykonano im zdjęcia w każdej fazie rozwojowej, następnie poddano je obróbce graficznej. W programie Scan2Cad, zdjęcia przekształcono na obraz wektorowy, następnie przy użyciu programu AutoCad 2014, odczytano wielkość rzutu badanych powierzchni. Powierzchnie całkowite roślin wyznaczono po określeniu wielkości rzutów pionowych i poziomych roślin. Stwierdzono, że po zastosowaniu rozpylacza DF 120-02 uzyskano lepsze pokrycie opryskiwanych roślin w każdej fazie rozwojowej i przy wszystkich stosowanych parametrach opryskiwania w porównaniu do rozpylacza XR 110-02. Nie stwierdzono istotnego statystycznie wpływu nanopierwiastka na wartość średniego całkowitego pokrycia powierzchni roślin rzepaku ozimego.
***Słowa kluczowe**: stopień pokrycia, nanomiedź, nawóz dolistny, opryskiwanie roślin, rozpylacz, morfologia rośliny*

1. Introduction

Researchers in many studies show that foliar fertilizers play an important role in increasing yields and improving plant health by reducing their infection by diseases or pests [1, 14]. In agriculture, nanotechnology is being used more and more frequently, which allows introducing new potentially more effective plant protection chemicals, artificial fertilizers or growth regulators from the information provided by manufacturers [8, 11-13].

It should be remembered that when spraying crops with crop protection products or foliar fertilizers, it is important to achieve maximum biological effectiveness while minimizing the risk posed by the use of chemical plant protection (elimination of spray drift and thus contamination of the environment, including the surface and underground water or other non-target damage). The problem of modern agriculture consists in the use of too high doses of mineral fertilizers and plant protection products whose residues are dispersed in soil and water. Residues of chemical compounds in the environment pose a threat to the entire ecosystem. Therefore, it is very important to perform an effective spraying operation while limiting the harmful effects of chemical substances on the environment and living organisms.

The sprayed plants differ not only in morphological features, but above all in the degree of exposure on the sprayed stream and the ability to absorb the usable liquid. Horizontal surfaces are usually several times more exposed to the deposition of the active substance contained in plant protection products or in liquid fertilizers compared to the deposition to vertical surfaces [10]. Linking indicators defining the quality of the spraying operation, such as the degree of coverage or deposition of the active substance to the plants, with the size of the sprayed surface or plant development phase will result in a reduction in the use of agrochemicals in crop protection and a more efficient and effective plant protection treatment. This will contribute to the protection of the environment, including surface and underground waters.

The aim of the study was to determine the average total coverage of winter rapeseed surface sprayed with copper foliar fertilizer and nano-copper with selected parameters of the spraying process and to determine the total plant surface in three development stages (12, 14 and 16 BBCH).

2. Materials and methods

The research was carried out at the Institute of Soil Science and Plant Cultivation, National Research Institute, Department of Weed Science and Tillage Systems in Wroclaw, in two stages. First of all, the degree of coverage research was carried out, the 'Aporo1' chamber was used for spraying. The experiment was carried out in three replications, placing three artificial plants on the chamber treatment table. The samplers (Water Sensitive Paper - WSP) of the Albuz company with the surface of 2,5 x 7,5 cm^2 were placed on the artificial plants. The samplers were attached to horizontal surfaces (upper and lower) and vertical surfaces (approach, leaving, left and right) of the artificial plants. The air temperature in the laboratory during spraying was 20°C, and humidity 60%. The following parameters of the spraying process were adopted:

- spraying speed: 0.86 $m \cdot s^{-1}$,
- liquid pressure: 0.20 and 0.28 MPa,
- two conventional nozzles: flat fan XR 110-02 and double flat fan DF 120-02,
- spraying height: 0.5 m,
- samplers were sprayed with the following preparations: foliar fertilizer Mikrovit Copper 80 and a preparation containing copper oxide nanoparticles (nano-powder, <50 nm, Sigma-Aldrich);
- dose of the preparation: 160 $gCu \cdot ha^{-1}$,
- dose of the usable liquid: 250 and 300 $L \cdot ha^{-1}$.

The degree of coverage was determined by a computer method of image analysis in accordance with the methodology described in Dereń et al. [2]. Then, the average degree of coverage of horizontal surfaces ($Pmedium_{Ashp}$) and the average degree of coverage of vertical surfaces ($Pmedium_{Asvp}$) were calculated.

In the second stage of the research, a greenhouse experiment was established. In the pots, winter oilseed rape of the DK EXTROVERT F1 variety was sown according to the methodology described in Dereń et al. [3]. The studies included three independent series of experiments, three replicates in each series. When the plants reached the assumed developmental stage: 12 BBCH (2 leaves), 14 BBCH (4 leaves), 16 BBCH (6 leaves),the photos of horizontal and vertical surfaces of the tested plants were taken with a photographic camera Nikon D90 set horizontally and vertically, always at the fixed distance from the plant. Photographs of vertical surfaces were taken six times, rotating the plant by 60°, thus rotating the plant by 360°. To read the surface of the projections of the studied plants, the photos were processed graphically. For this purpose, the Scan2Cad program was used, in which the images were transformed into a vector image. Then, using the AutoCad 2014 program, the photos were scaled to the actual size, and the surface of the projections of the examined plants in cm² were read. The results of the six vertical surfaces projections were averaged to obtain one value defining the size of the vertical projection surface. The size of the vertical projection (A_{svp}) is the sum of 4 average surfaces: left, right, approach and leaving. The size of the horizontal projection (A_{shp}) was averaged for two surfaces: upper and lower.

The next step was to determine the average total coverage of the surface (P_c) of winter oilseed rape plants in the studied development phases, which were calculated according to the formula 1:

$$P_c = \frac{A_{shp} \times P_{medium_{Ashp}}}{100\%} + \frac{A_{svp} \times P_{medium_{Asvp}}}{100\%} \quad (1)$$

where:

Pc –average total coverage of the plant surface with usable liquid (cm²),

A_{shp}–surface horizontal projection (cm²),

A_{svp}–surface vertical projection (cm²),

$Pmedium_{Ashp}$ –average coverage of the horizontal projection surface (%),

$Pmedium_{Asvp}$ –average coverage of the vertical projection surface (%).

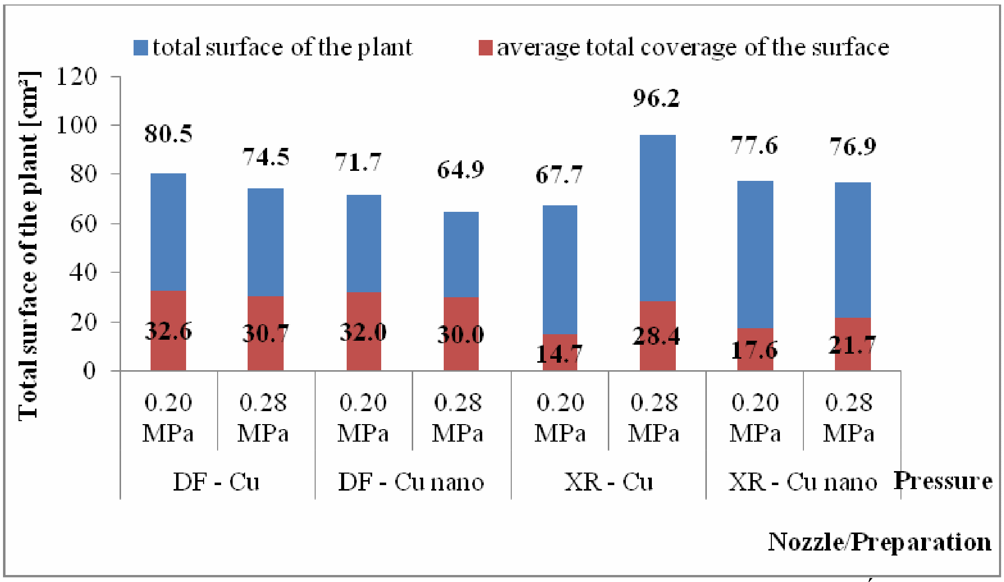
The results of the study were subject to statistical analysis in the Statistica 12.5 program. Shapiro-Wilk normality tests and variance homogeneity tests (Levene) were performed on the basis of which it was found that the dependent variable (mean average total coverage of the surface P_c) meets the applicability conditions of the multivariate analysis of variance for the 12 and 14 BBCH development phase of winter rape, but it does not meet it for the 16 BBCH development phase. For this reason, to determine the effect of the factors (nozzle, pressure, type of preparation) on the mean average total coverage of the surface (P_c) for the 12 and 14 BBCH phase, the multivariate analysis of variance (ANOVA) was performed, while for the 16 BBCH phase, the non-parametric Mann-Whitney U test was used. The tests were performed at the significance level of α=0.05.

3. Results and discussion

The results of studies on the average total coverage of the surface (P_c) of winter rape plants in the studied development phases on the background of the entire plant surface are shown in Fig 1-3. The method used to measure the degree of coverage showed minute traces of droplets on the samplers attached to the lower horizontal surface of the artificial plant. In similar studies, other scientists have observed the coverage of the lower surface of leaf blades and the increase in the degree of coverage, but during studies performed using nozzles with an auxiliary air stream [5-6].

On the basis of the conducted research, it was observed that the use of the double flat fan nozzle DF 120-02 for spraying winter rape resulted in higher mean average total coverage of the surface (P_c), regardless of the development phase, type of preparation and pressure, with which the procedure was performed (Fig. 1-3).

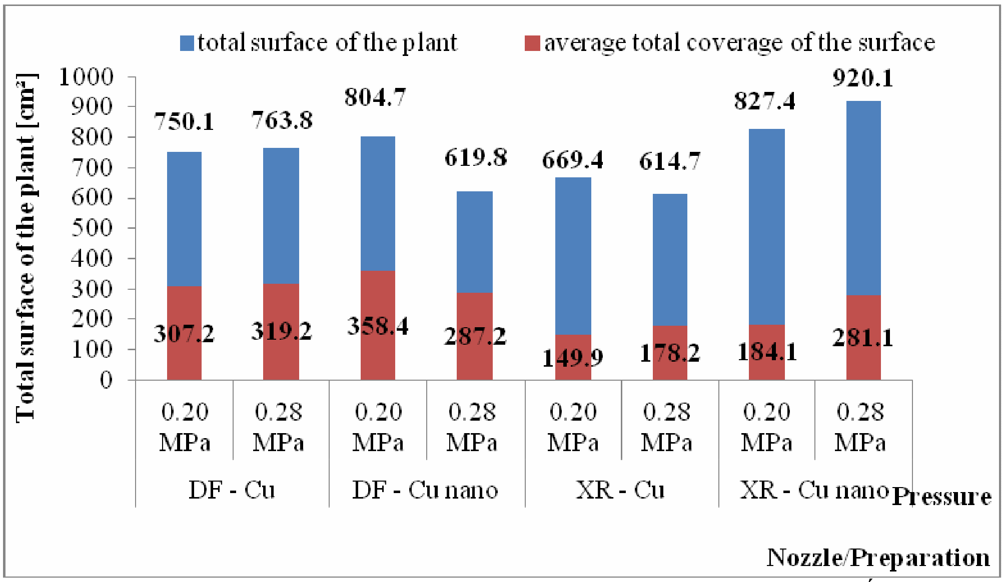
In general, higher mean average total coverage of the surface (P_c) of winter rape (compared to the surface of the whole plant) was observed using a preparation containing a nano-element for spraying plants, compared to the Mikrovit Copper 80 foliar fertilizer. For the DF 120-02 nozzle, at a pressure of 0.28 MPa, using the nano preparation for spraying rape resulted in higher mean total coverage of the plant surface by 5.8% (Fig. 3) compared to the value obtained for the Mikrovit Copper 80 foliar fertilizer. While for the XR 110-02 nozzle, the average total coverage of the surface with the nano-copper preparation was higher by 3.4% compared to the coverage of plants with foliar fertilizer at a pressure of 0.20 MPa for the development phase 16 BBCH (Fig. 3). The highest value of the average total coverage of winter oilseed rape (46.8%) was recorded for the 16 BBCH development phase when spraying the plants with the preparation with nano-copper and double flat fan nozzle DF 120-02 at a pressure of 0.28 MPa, the lowest (21.2%) for the XR 110-02 nozzle at a pressure of 0.20 MPa and 16 BBCH development phase when spraying plants with a Mikrovit Copper 80 foliar fertilizer.



Source: own elaboration / Źródło: opracowanie własne

Fig. 1. Total coverage (P_c) of winter oilseed rape, in development stage 12 BBCH for the selected parameters of the spraying process. Cu – Mikrovit Copper 80 foliar fertilizer; Cu nano – preparation containing nano-copper; XR- flat fan nozzle XR 110-02; DF - double flat fan nozzle DF 120-02

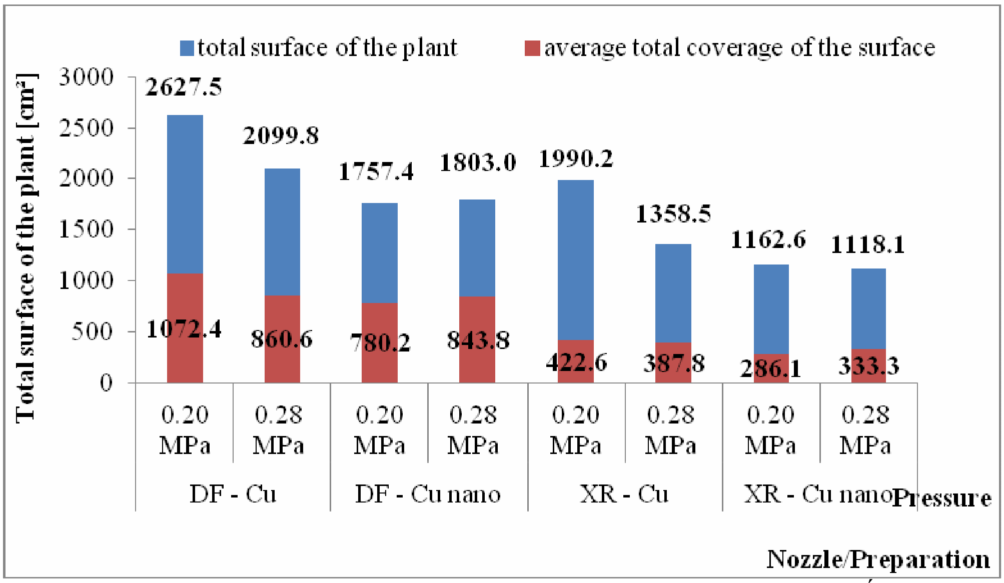
Rys. 1. Całkowite pokrycie (P_c) rzepaku ozimego, w fazie rozwojowej 12 BBCH dla wybranych parametrów procesu opryskiwania. Cu - nawóz dolistny Mikrovit Miedź 80; Cu nano - preparat z zawartością nanomiedzi; XR - rozpylacz jednostrumieniowy XR 110-02; DF - rozpylacz dwustrumieniowy DF 120-02



Source: own elaboration / Źródło: opracowanie własne

Fig. 2. Total coverage (P_c) of winter oilseed rape in the 14 BBCH development phase for the selected parameters of the spraying process. Cu – Mikrovit Copper 80 foliar fertilizer; Cu nano – preparation containing nano-copper; XR - flat fan nozzle XR 110-02; DF - double flat fan nozzle DF 120-02

Rys. 2. Całkowite pokrycie (P_c) rzepaku ozimego w fazie rozwojowej 14 BBCH dla wybranych parametrów procesu opryskiwania. Cu - nawóz dolistny Mikrovit Miedź 80; Cu nano - preparat z zawartością nanomiedzi; XR - rozpylacz jednostrumieniowy XR 110-02; DF - rozpylacz dwustrumieniowy DF 120-02



Source: own elaboration / Źródło: opracowanie własne

Fig. 3. Total coverage (P_c) of oilseed rape in the 16 BBCH development phase for the selected parameters of the spraying process. Cu – Mikrovit Copper 80 foliar fertilizer; Cu nano – preparation containing nano-copper; XR - flat fan nozzle XR 110-02; DF - double flat fan nozzle DF 120-02

Rys. 3. Całkowite pokrycie (P_c) rzepaku ozimego w fazie rozwojowej 16 BBCH dla wybranych parametrów procesu opryskiwania. Cu - nawóz dolistny Mikrovit Miedź 80; Cu nano - preparat z zawartością nanomiedzi; XR - rozpylacz jednostrumieniowy XR 110-02; DF - rozpylacz dwustrumieniowy DF 120-02

Based on the analysis of the results of the multivariate analysis of variance ANOVA (Tab. 1) and Mann-Whitney U (Tab. 2), a significant effect of the nozzle type that was used for spraying operation was found on the value of the mean average total coverage of the surface of winter rape plants in all studied development phases.

Table 1. Results of multivariate coverage variance analysis (P_c) for development phase 12 and 14BBCH of winter rape
Tab. 1. Wyniki wieloczynnikowej analizy wariancji pokrycia (P_c) dla fazy rozwojowej 12 i 14BBCH rzepaku ozimego

Factors	Value p	
	Rape development phase	
	12 BBCH	14 BBCH
Nozzle	0,0005	0,0006
Preparation	0,6934	0,2169
Pressure	0,1737	0,6721

Source: own elaboration / Źródło: opracowanie własne

Table 2. Results of Mann-Whitney U test of coverage (P_c) for development phase 16 BBCH of winter rape
Tab. 2. Wyniki testu Mann-Whitney U pokrycia (P_c) dla fazy rozwojowej 16 BBCH rzepaku ozimego

Factors	Value p
Nozzle	0,0004
Preparation	0,9310
Pressure	0,3708

Source: own elaboration / Źródło: opracowanie własne

On the basis of the statistical analysis, it was found that the type of preparation does not have a significant impact on the total coverage (P_c) irrespective of the parameters of the spraying process and the development phase of the plant. The statistical analysis carried out did not show any significant influence of pressure on the dependent variable (P_c). Based on the analysis of Figs 1-3 and the statistical analysis, it can be concluded that the pressure increase up to 0.28 MPa, during the spraying operation does not significantly affect the total coverage of winter rape plants in the examined development phases. We can therefore reduce the consumption of usable liquid by successfully spraying at a lower pressure without increasing the liquid dose. In the case of coverage tests, a higher liquid dose should be manifested by a significant increase in the coverage level. Many scientists investigated the effect of pressure, the speed of the nozzle, the change in the nozzle angle in the longitudinal and perpendicular plane to the substrate on the value of the degree of coverage. The selection of the right nozzle is a prerequisite for properly spraying and thus the degree of coverage [7, 9].

The winter rape plants depending on the development phase differ significantly in the size of the surface to be sprayed, while the average total coverage surface (P_c) is kept constant (not exceeding the 1% difference between the individual development phases) for the DF 120-02 nozzle. A similar phenomenon was observed for the flat fan nozzle XR 110-02, with the exception of spraying carried out at a pressure of 0.20 MPa and Mikrovit Copper 80 foliar fertilizer, where the total coverage (P_c) in the 14 BBCH development phase was higher by 1.2% from the value recorded for the 16 BBCH phase (Fig. 2 and 3). The difference in the average total coverage surface for the XR 110-02 nozzle and the preparation containing nano-copper at a pressure of 0.20 MPa was 1.9% (between the 16 BBCH and 12BBCH phase) (Fig. 1 and 3) and 2.4% (between the 16 BBCH and 14 BBCH phase) (Fig. 1 and 2). While for the pressure of 0.28 MPa, the difference in coverage of the total surface with the preparation containing nano-copper was 2.3% between the 14 BBCH and 12 BBCH phase (Fig. 2 and 1).

Dereń et al. [3] conducted research on the deposition of copper to winter oilseed rape in various development phases, the authors observed that the value of copper deposited to plants depends on the development phase, and decreases with the growth of the plant. The highest values of incorporation have been noted for the 12 BBCH development phase of winter rape. Therefore, we can conclude that the values of plant coverage obtained during spraying with copper preparations are not significantly related to the amount of active substance absorbed by the plants.

Drocas et al. [4] drew attention to the fact that plant morphology is an important element in determining the degree of coverage. They carried out an experiment aimed at determining coverage of horizontal and vertical surfaces by various types of nozzles, using water-sensitive paper samplers. They found that for monocotyledonous plants, a better coverage can be obtained using double flat fan nozzles, while for plants with a predominance of horizontal (dicotyledonous) surfaces, flat fan nozzles can also be successfully used. The highest levels of coverage of horizontal and vertical samplers were obtained during spraying with the double flat fan nozzle DF 120-04 [4]. In the discussed own research, the authors also included plant morphology and calculated the average total coverage surface of dicotyledonous plant (winter oilseed rape) in three development phases. It was observed that the use of the double flat fan nozzle DF 120-02 for the procedure results in a higher coverage compared to a flat fan nozzle XR 110-02, regardless of the spraying process parameters.

Other researchers came to similar conclusions, who, when examining the degree of coverage of vertical and horizontal surfaces, showed that the size of this parameter depends, among others, on the type of the nozzle used for the procedure and the spraying speed. They showed, just like the authors, that flat fan nozzles perform a poorer coverage of vertical surfaces, while double flat fan nozzles of horizontal ones [15-16].

4. Conclusions

1. Higher values of the average total coverage (P_c) of winter oilseed rape in all studied development phases were noted during the spraying of plants with the double flat fan nozzle DF 120-02 regardless of the spraying process parameters, in comparison to the flat fan nozzle XR 110-02.
2. Based on the results of the statistical analysis, it can be concluded that the use of the preparation with nano-copper for spraying winter oilseed rape in the studied development phases (12, 14 and 16 BBCH) does not significantly improve the plant coverage.
3. The average total coverage (P_c) of winter oilseed rape depends mainly on the type of the nozzle used for spraying.

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