

# PRIMJENA UMJETNIH NEURONSKIH MREŽA U MODELIRANJU PARAMETARA PRSKANJA PRI RAZLIČITIM KINETIČKIM UVJETIMA

## SAŽETAK

Učinkovitost primjene sredstava za zaštitu bilja u poljoprivredi uvjetovana je, osim pravilnim odabirom pesticida također i kvalitetom rada strojeva i opreme kojom se zaštita obavlja. Kvaliteta rada strojeva, uz pretpostavku tehničke ispravnosti, ovisi o kinetičkim čimbenicima: brzini kretanja prskalice i kutu usmjeravanja kapljica škropiva. U radu su istraživana, prema standardnim metodama, pokrivenost ciljane površine, pokrivenost ne ciljane površine, spektar veličine kapljica s obzirom na brzinu kretanja prskalice i kuta usmjerenja mlaznica. Cilj ovog rada bio je optimizirati te parametre kako bi se postigla maksimalna učinkovitost suzbijanja štetnika uz minimalne gubitke (zanošenje).

Istraživanje je provedeno na ravnoj površini (praktikum VUK) korištenjem traktorske prskalice Agromehnika AGS 600EN s mlaznicama Lechler 110 04 ST. Ispitivan je utjecaj tri radne brzine (6–7,9 km/h, 8–9,9 km/h i 10–12 km/h) te tri kuta prskanja ( $-30^\circ$ ,  $90^\circ$  i  $+30^\circ$ ) na pokrivenost ciljane (CP) i ne ciljane površine (NCP) te na promjer kapljica. Za prikupljanje podataka korišteni su vodoosjetljivi papirići (VOP), a analiza slike provedena je softwareom DepositScan. Dobiveni podaci obrađeni su statističkim metodama (ANOVA, Tukey HSD test) te modelirani pomoću umjetnih neuronskih mreža (UNM), točnije višeslojnog perceptrona (MLP), čija je preciznost uspoređena s klasičnom linearnom regresijom.

Rezultati su pokazali da kinetički uvjeti značajno utječu na kvalitetu aplikacije:

Brzina kretanja: Povećanjem brzine kretanja smanjuje se pokrivenost tretirane površine (PTP), ali se smanjuje i promjer kapljica. Niže brzine (6–7,9 km/h) osigurale su bolje zadržavanje sredstva na ciljnoj površini.

Kut prskanja: Pozitivan kut mlaznica ( $+30^\circ$ , usmjeren prema naprijed) ostvario je najveću pokrivenost ciljane površine i stvorio sitnije kapljice, što omogućuje bolju raspodjelu sredstva. Suprotno tome, negativni kut ( $-30^\circ$ ) rezultirao je manjom pokrivenošću i krupnijim kapljicama.

Zanošenje (ne ciljane površina): Najveći rizik od zanošenja (pokrivenost NCP) zabilježen je pri većim brzinama i negativnom kutu ( $-30^\circ$ ), dok je kut od  $+30^\circ$  pokazao najmanje gubitke na ne ciljanim površinama.

Razvijeni model umjetnih neuronskih mreža (MLP 8-10-1) pokazao se znatno superiornijim u predviđanju parametara prskanja u odnosu na linearnu regresiju. UNM model postigao je koeficijent determinacije  $R^2 > 0,98$  za pokrivenost površine, uz minimalnu pogrešku (RMSE = 1,85), dok je linearni model imao  $R^2$  od svega 0,02 i znatno veću pogrešku (RMSE = 14,82). Ovo potvrđuje da je proces prskanja izrazito nelinearan i da UNM uspješno modelira složene interakcije između brzine, kuta i površine.

Istraživanje je potvrdilo da se primjenom UNM-a može s visokom točnošću predvidjeti kvaliteta prskanja.

Hipoteza 1 (da se najveća pokrivenost postiže pri 6–7,9 km/h i kutu  $+30^\circ$ ) je djelomično potvrđena; ta kombinacija daje najbolju pokrivenost, ali ne nužno i najuži raspon kapljica.

Hipoteza 2 je u potpunosti potvrđena: pogreška procjene modela UNM značajno je manja od pogreške linearne regresije.

Praktični doprinos rada ogleda se u smjernicama za podešavanje prskalice: korištenje kuta od  $+30^\circ$  pri nižim brzinama preporučuje se za optimalnu učinkovitost i smanjenje

onečišćenja okoliša. Model UNM predstavlja robustan alat za preciznu poljoprivredu koji omogućuje optimizaciju parametara prskanja u realnim uvjetima te nudi praktične smjernice poljoprivrednicima za racionalniju primjenu pesticida uz manji rizik za okoliš.

**Ključne riječi:** prskanje, kinetički uvjeti, umjetne neuronske mreže

# APPLICATION OF ARTIFICIAL NEURAL NETWORKS IN MODELLING SPRAY PARAMETERS UNDER DIFFERENT KINETIC CONDITIONS

## EXTENDED SUMMARY

Application of artificial neural networks in modeling spray parameters under different kinetic conditions

**Introduction:** The introductory part of the paper emphasizes the importance of protecting vegetable and field crops with technological procedures that reduce the impact of diseases, weeds and harmful organisms without damaging the environment. Directive 2009/128/EC sets guidelines for the sustainable use of pesticides, with strict monitoring and reduction of their use. Pests cause significant losses in global agriculture, which is why the effective and responsible use of pesticides is necessary. Chemical control remains a key element of modern production, but carries risks to human health and the environment. Therefore, research is focused on optimizing the use of pesticides, especially through the development of machines, equipment and nozzles that enable precise distribution, reduced energy consumption, higher work efficiency and minimal soil compaction. Special attention is paid to controlling droplet size and their uniformity, which significantly affects the effectiveness of the treatment and the risk of drift.

The introduction also emphasizes the importance of precision agriculture, which, using GPS technology, sensors, unmanned aerial vehicles and computer models, enables targeted application of agents and a reduction in overall pesticide consumption. Various studies analyze the spectrum of droplet sizes, the influence of nozzles, spray additives, meteorological conditions and plant morphology on droplet behavior and target surface coverage. Additionally, advanced materials such as superhydrophobic surfaces and new environmentally friendly pesticide formulations that increase stability and efficacy with reduced risks to the environment and humans are being studied. In general, the introduction emphasizes that precise application, proper equipment design and understanding of droplet dynamics play a key role in achieving effective and sustainable crop protection.

**Material and methods:** The research examined the influence of technical factors on the quality of spraying under controlled conditions on a flat surface of the VUK practicum. The focus was placed on assessing the coverage of the target and non-target surface, the droplet size spectrum, and the influence of the operating speed of the aggregate and the angle of the nozzles on the kinetics of the droplets. For the purposes of the research, an Agromehanika AGS 600EN tractor sprayer was used, structurally adapted to enable changing the angle of the nozzles in three positions:  $-30^\circ$ ,  $90^\circ$  and  $+30^\circ$ .

During the experiment, microclimatic conditions – temperature, relative humidity and air flow velocity – were continuously monitored. Kinetic conditions were defined by operating speeds of 6–7.9 km/h, 8–9.9 km/h and 10–12 km/h, which reflect the usual exploitation conditions of pesticide application. The coverage of the treated surface (PTP) and the number of droplets per unit area were determined by analyzing water-sensitive papers (VOP) measuring 26 × 76 mm. Image analysis was performed using the DepositScan software.

Statistical analysis included the use of linear regression models and artificial neural network (ANM) models to assess the impact of operating speed and nozzle angle on

PTP and droplet diameter. The analysis was performed in the TIBCO Statistica 13.3.0 program. The results are presented as mean values and standard deviations, with one-factor and multifactor ANOVA and Tukey HSD post hoc test.

The research also applied artificial neural networks due to their effectiveness in modeling nonlinear processes and large data sets. A multilayer algorithm consisting of an input, hidden and output layer was used. ANM models enabled a precise assessment of the relationship between the speed of movement, nozzle angle and the resulting values of PTP and droplet diameter. Yoon's sensitivity equation was used to optimize the model, which determined the relative importance of individual input variables.

**Result and conclusions:** After processing the scanned VOPs in the DepositScan software, the values of the treated surface coverage (PTP) and the average droplet diameter ( $\bar{x}$ ) were obtained for three aggregate speeds and three nozzle angles. The results shown in the tables are based on a total of 120 processed VOPs, which provides high reliability of the average values.

Combinations of different speeds and nozzle angles determined variations in the droplet distribution, with the lowest speeds and positive nozzle angles (especially +30°) resulting in greater coverage of the target surface. At the same time, the results of the non-target surface (NCP) show significantly greater oscillations, indicating that losses outside the target zone strongly depend on the operating parameters. The data were analyzed using statistical methods (ANOVA and Tukey HSD), which confirmed the differences between groups and the significant influence of the investigated factors.

Descriptive statistics included the analysis of: three travel speeds (6–8, 8–10, 10–12 km/h), two surface categories (CP and NCP) and three nozzle angles (–30°, 30°, 90°). Main observed characteristics: NCP shows greater oscillations compared to CP, which means that the losses of the product outside the target zone vary strongly depending on the combination of speed and angle. Lower speeds give higher PTP values, which confirms the hypothesis that lower speed increases the precision and uniformity of application.

The angle of +30° in combination with lower speeds systematically provides the highest coverage, which supports the confirmation of the first hypothesis.

The results of the ANOVA test confirm: all main factors (speed, surface, angle) have a statistically significant effect on PTP and droplet diameter ( $p < 0.01$ ), all interactions are also significant, which means that the factors do not act in isolation — their combinations additionally modify the results.

These findings confirm the need to include nonlinear relationships when developing UNM models.

An MLP 8-10-2 ANN model was developed, and its performance was evaluated using the coefficient of determination ( $R^2$ ) and the sum of squared errors (SOS):  $R^2 = 0.99$  (training), 0.98 (testing), 0.98 (validation).

The model shows exceptionally high accuracy and generalization ability, with low SOS (1.99 and 1.74) indicating stability and minimal error. The optimization was performed using the BFGS algorithm, using an exponential function in the hidden layer and an identity in the output layer. These findings provide practical guidelines for the optimization of spraying parameters and confirm the suitability of the ANN model for predicting PTP and droplet diameter.

**Keywords:** spraying, kinetic conditions, artificial neural networks