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APPLICATION AND EVALUATION OF PERFORMANCE QUALITY OF HOSE-REEL IRRIGATION MACHINE

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Considering the global tendency in water saving, this research is focused on practical measurements of even distribution of water. The performance quality is determined by values of coefficients of distribution uniformity and non-uniformity given in percentages. Objects of investigation were belt irrigators with varying input conditions (seven pieces). Testing of hose-reel irrigators took place in Southern and Western Slovakia. Tests were carried out during irrigation of selected agricultural crops (potatoes, vegetables); in these areas, rainwater vessels were distributed at a spacing of 1 or 2 m, perpendicular to the direction of movement of the bracket or tripod with a gun sprinkler. The input conditions, such as machine specifications and weather conditions, were monitored and evaluated for all variants. The data were also analysed along with the linear model through statistical analysis software – one-way analysis of variance ANOVA. Considering the results, it is possible to conclude that there were recorded statistically significant differences for uniformity coefficients, depending not only on the site but also on the specific evaluation methodology ($P > 0.05$). If the input conditions (site, type of irrigator, sprinkler) were changed, the effect of dependence was demonstrated to a much greater extent ($P < 0.05$, $F = 7.08 > F_{crit}$). The results of the non-uniformity coefficients confirmed the statistically significant differences not only in the sample sets of coefficients but also in the selection sets of conditions.

Keywords: performance quality; irrigation uniformity; ANOVA; hose-reel irrigation machine; level of non-uniformity; variation coefficient

Agricultural crops can only be grown in areas with suitable climatic conditions, both in terms of temperature and water. Unsatisfactory climatic conditions result in low harvest and in cases of particularly poor climatic conditions, crops can be completely destroyed. The need for irrigation in individual areas and regions of the Slovak Republic is determined primarily by the deficit of water precipitation and the annual distribution of rainfall, but also by other climatic factors, e.g. air temperature and saturation supplement (Hennyeyová and Palková, 2006; Jobbágy et al., 2008). In order to achieve the most even and sufficient harvest of irrigated crops, the performance quality of irrigators needs to be at a high level. This can only be achieved by regular maintenance and inspection of nozzles and sprayers (Jobbágy, 2011; Dechmi et al., 2003a). On the other hand, irrigation uniformity guarantees appropriate moisture conditions for the crop (Látečka, 2000). Several indicators are used to assess the performance quality, ranging from visual inspection to evaluation through methodologies and standards (Jobbágy et al., 2013; Topak et al., 2005). In case of application of any of the methodologies utilized in this paper, irrigation dose was obtained from precipitation vessels (Topak et al., 2005; Jobbágy et al., 2013). According to Tomášik and Jobbágy (2013), Christiansen's spray uniformity coefficient below 84% of the set value indicates a low quality performance. Numerous authors suggest that wind velocity is one of the main influencing factors in terms of the quality of irrigation techniques (Dechmi

et al., 2003a). Solomon (1979) stated that the uniformity coefficient depends on the structure system variables (irrigator brand, nozzle size and type, nozzle pressure and spacing) and the major uncontrollable variable – wind speed (Temizel, 2016). The uniformity of application of the irrigation rate also affects the variability of soil moisture (Abbaspour-Gilandeh et al., 2018).

In addition to the uniformity of the moisture distribution, the resulting quality of the irrigation technique also affects the crop yield (Li and Rao, 2000; Dechmi et al., 2003b; Jobbágy et al., 2013). Standard of performance quality assessed by the spray uniformity coefficient should exceed 90%. Considering the performance quality assessment utilizing a non-uniformity coefficient, the value should be less than 10% (Jobbágy and Krištof, 2018; ASAE, 1998).

Generally, literature makes it clear that several methods of assessing the quality of irrigation machines are used in practice, e.g. uniformity coefficient, non-uniformity coefficient, degree of uniformity, and coefficient of variation (De Menezes et al., 2015). Results thus differ in values depending on the equation used to assess spray uniformity in the same studied areas. Sprinkler irrigation is becoming a preferred method if the available water for irrigation becomes scarce (Uddin et al., 2013).

The aim of the study is to compare selected coefficients of uniformity under several field conditions and to point out the possibilities of application of the studied types of result assessment on selected hose-reel irrigation machines.

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Material and methods

Given the global climate change and water-saving issue, this paper evaluates the quality of irrigation techniques and compares different methods of evaluating the performance quality. In recent years in Slovakia, irrigation of agricultural crops has been representing one of the most important stages in the harvest production. The irrigation dose was applied over several irrigation seasons and years, with crops being predominantly potatoes and vegetables (carrots). Depending on the location of field experiments, there were various soil types – sandy loams and loamy sands. Fig. 1 shows the locations where experimental measurements were performed. The agricultural enterprise Agrocoop a.s. Imeľ is situated in the southwest of Slovakia in the district of Komárno (from F1 to F4 experimental fields). Terrain of agricultural enterprise is plane with the slope from 0 to 2°. The

Fig. 1 Locations under investigation in western region of Slovakia

first explored field is classified by BPEJ 04003 – the muck; medium soil depth; pH 7.78; strongly alkaline. The second agricultural enterprise was Paulis, Záhradkársky služby (F5 – experimental field). The main focus of the company

is purchase and sale of vegetables and fruits, as well as import of southern fruit and supply of retail outlets. The third agricultural enterprise was PD Kukučínov (F6 and F7 experimental fields) where irrigation technology is

Table 1 Irrigation machine technical data and selected parameters

Experimental field	Irrigation machine technical data						Weather conditions	
	type	L (m)	D _H (mm)	Type of sprinkler	K	M _d (mm)	v _w (m·s ⁻¹)	T (°C)
F1	BauerRainstar 85Tx	300	90	Gun Komet TWIN 140	70	15.19	0.5	29
F2	BauerRainstar 85Tx	300	90	Gun Komet TWIN 140	61	23.77	1	28
F3	BauerRainstar 85Tx	300	90	Gun Komet TWIN 140	30	24.18	1.5	30
F4	BauerRainstar 85Tx	300	90	Gun Komet TWIN 140	30	31.6	1.5	29
F5	Cipa 600 GX	300	110	boom	59	18.27	1	28
F6	Cipa 600GX	300	110	Gun Komet TWIN 140	34	25.79	1.2	25
F7	Cipa 600GX	300	110	Gun Komet TWIN 140	30	26.48	1.5	27

D_H – hose diameter; L – hose length; K – number of cups; M_d – irrigation rate; v_w – maximum wind speed; T – temperature, °C

Fig. 2 Example of irrigation uniformity test using rain gauge for measuring uniformity coefficient

used only if necessary. Average annual rainfall ranges from 500 to 550 mm.

Used irrigators

Fields were irrigated with hose-reel irrigation machines equipped with new or reconditioned distributors of irrigation water (Fig. 2). In the majority of cases, the source of water was groundwater or lake. The main irrigation system consisted of a stationary or mobile pump that was adapted to a tractor. The technical parameters of the input irrigators and the weather conditions for specific measurements are given in Table 1.

Performance quality

Performance quality assessment – the test of uniformity – was conducted by means of precipitation gauges to assess the spray uniformity. The rain gauge vessels had a diameter of 115 mm and total height of 100 mm. Vessels were placed on a tripod with a gun sprinkler or a bracket.

Irrigation assessment was performed in accordance with several methods proposed by Látečka (2000); Maroufpoor et al. (2010); Jobbágy (2011); Topak et al. (2005). Staebner (1931) started to evaluate the spray uniformity and based his assessments on the rule that the maximum spray intensity should not be more than twice the minimum, except for the marginal zone. On the basis of the measurement of precipitation heights in rain gauge vessels, he constructed isograms (lines with the same rainfall) and assessed the uniformity visually as very good, good, satisfactory, and bad.

Oehler (1932) assessed the uniformity of water distribution by the degree of non-uniformity U as a proportion of maximum and minimum intensity. In another work, Oehler (1933) used the value of average deviation A , which can be calculated as the average error of individual precipitation rate from their arithmetic mean. The value of non-uniformity is calculated as follows (for comparison with other results given in percentage):

$$a = \frac{A}{N_m} \cdot 100 \quad (\%) \quad (1)$$

where:

N_m – average value (mm)
 A – average deviation (mm)

To compare this value with uniformity coefficients, it is suggested to introduce the spray uniformity value a_r calculated according to the following equation:

$$a_r = 100 \left(1 - \frac{A}{N_m} \right) \quad (\%) \quad (2)$$

For all tested irrigators, Oehler's method (1933) was used as the first.

The following assessments of the performance quality of hose-reel irrigators were carried out according to Heermann and Hein (in ASAE, 1998), Christiansen (in Zdražil and Spitz, 1966), Wilcox and Swailes (1947) and Voight (1962). Calculation of the uniformity coefficient of the CUH spray according to the method by Heermann and Hein is given by:

$$CUH = 100 \left[1 - \frac{\sum_{i=m}^n \{S_i |V_i - \bar{V}|\}}{\sum_{i=m}^n V_i \cdot S_i} \right] \quad (\%) \quad (3)$$

$$\bar{V} = \frac{\sum_{i=m}^n V_i \cdot S_i}{\sum_{i=m}^n S_i} \quad (\text{mm}) \quad (4)$$

where:

- n – number of rain gauge vessels
- i – number necessary to identify a specific rain gauge vessel beginning with $i = 1$ for the vessel closest to the pivot and ending with $i = n$ for a rain gauge vessel located furthest from the pivot
- V_i – irrigation dose in the i -th rain gauge vessel, mm
- S_i – distance of the i -th rain gauge vessel from the pivot (m)
- $\bar{V}$ – average irrigation dose (mm)
- $|V_i - \bar{V}|$ – the absolute value of deviations from an average dose (mm)

The most widespread method for assessing the belt irrigators is spray uniformity evaluation by the uniformity coefficient CU according to Christiansen (in Zdražil and Spitz, 1966):

$$CU = 100 \left[1 - \frac{\sum_{i=1}^n |V_i - \bar{V}|}{n \cdot \bar{V}} \right] \quad (\%) \quad (5)$$

where:

- V_i – irrigation dose in the i -th rain gauge vessel (mm)
- $\bar{V}$ – average irrigation dose (mm)
- n – number of rain gauge vessels, i.e. the number of elementary areas to which the surface is divided

Wilcox and Swailes (1947) suggested a uniformity coefficient C_{ws} as follows:

$$C_{ws} = 100 \left[1 - \frac{\sigma}{\bar{V}} \right] \quad (\%) \quad (6)$$

where:

- σ – standard deviation (mm)
- $\bar{V}$ – average irrigation dose (mm)

In 1954, Stefanelli (in Lipták, 1971) suggested the usage of the variation coefficient C_v dependent on standard deviation σ and the average precipitation rate h_m (in accordance with our findings, the value is related to the spray uniformity coefficient value according to Wilcox and Swailes (1947); for the purposes of comparison, the value was converted to %):

$$C_v = \frac{\sigma}{h_m} \quad (\%) \quad (7)$$

Furthermore, evaluation of the performance quality by the coefficient of variation is also supported by the ASAE

standard (1998). In 1961, Hofmeister applied the degree of irregularity of E_f to evaluate the spray uniformity (the value is related to the uniformity coefficient value CU according to Christiansen, for the purposes of comparison, the value was converted to %):

$$E_f = \frac{\sum_{i=1}^n |h_i - \bar{h}|}{n \cdot \bar{h}} \cdot 100 \quad (\%) \quad (8)$$

where:

- E_f – degree of irregularity (%)
- $\bar{h}$ – average rainfall in the area being examined (mm)
- h_i – rate of rainfall at elementary surfaces (mm)
- n – number of elementary surfaces

Voight (1962) evaluates the spray uniformity by the degree of non-uniformity γ , taking into account the distance of the measured points from the sprayer r_i (for the purposes of comparison, the value was converted to %):

$$\gamma = \frac{\sum_{i=0}^n r_i |h_m - h_i|}{h_m \sum_{i=0}^n r_i} \cdot 100 \quad (\%) \quad (9)$$

where:

- γ – degree of non-uniformity (%)
- h_m – average rainfall in the area being examined (mm)
- h_i – rate of rainfall at elementary surfaces (mm)
- r_i – distance of the measured points from the sprayer (m)

Considering the possibility of result assessment by utilizing also the uniformity coefficient, it is possible to introduce the coefficient γ_r , which can be calculated as follows:

$$\gamma_r = 100 \left(1 - \frac{\sum_{i=0}^n r_i |h_m - h_i|}{h_m \sum_{i=0}^n r_i} \right) \quad (10)$$

- γ_r – degree of uniformity (%)

Evaluation of results

On the basis of the aforementioned, researchers exploit various methods to evaluate the quality of irrigation techniques, namely the spray uniformity coefficient, degree of non-uniformity and variation coefficient. This means that applied equations can lead to different results in terms of the uniformity of distributed water over the same elemental surfaces. The main aim of the paper is to evaluate the different coefficients proposed by individuals and to examine them in terms of the results acquired under field conditions. Finally, the results were evaluated by Duncan's test with a 95% confidence level. Thereby, single-factor analysis ANOVA (SAS, 2003) was used to evaluate and compare the results of different spray uniformity coefficients:

$$y_{ij} = \mu + C_i + e_{ij} \quad (\text{mm}) \quad (11)$$

where:

- y_{ij} – measured value
- μ – overall mean
- C_i – effect of uniformity coefficient
- e_{ij} – random error with mean 0 and variance σ^2

Results and discussion

Different coefficients determining the quality of the irrigation technique were used to assess the performance quality of hose-reel irrigators. Based on the established methodology, there were seven different input conditions, one of which included a combination of a sprinkler with a console. In other practical measurements, hose-reel irrigators with a tripod and a gun sprinkler were used. The most common evaluation of the irrigation performance quality of hose-reel irrigators is the one by Christiansen. In addition to this method, it was also decided to use four other spray uniformity coefficients CUH , C_{ws} , a_r and γ_r .

Utilization of performance quality evaluation by the non-uniformity coefficient is not frequent. That is why it was decided to evaluate the results in such a manner as well. For this reason, the coefficient of uniformity a_r was introduced within the application of non-uniformity a (Eq. 1) so that the results obtained can be comparable. Graphical representation of the results of the irrigation uniformity coefficients for seven different input conditions is shown in Fig. 3. They show different results with respect to input values and methods of determination, except for a_r and CU ($P = 1$, $F = 0 < F_{crit}$), indicating no significant difference between the values. Changes in the uniformity spray coefficient CUH by Heermann and Hein are a result of another calculation method taking into account the distance between a particular vessel and sprayer. However, when evaluating the results gained by combining the a_r , CU and CUH coefficients through the ANOVA, there is already a significant difference between the individual assessment methods ($P < 0.05$, $F = 6.41 > F_{crit}$). When evaluating all the coefficients, it was also observed that there was a significant alteration between the different assessment methods ($P < 0.05$, $F = 4.23 > F_{crit}$).

Considering the evaluation of the results on the basis of assessing the existence of rate dependence from field conditions, it was observed that there was also a significant difference ($P < 0.05$, $F = 7.08 > F_{crit}$). Therefore, research results indicate that, when using a statistical model in which different spray uniformity coefficients or different field conditions were determined as sample sets, they are both dependent. It is possible to clearly state that the impact of changes in field conditions, e.g. changes in specific irrigators, shows a stronger dependence in contrast to the assessment method (applied coefficient).

Furthermore, the set irrigation rate had also a clear impact on the resulting performance quality in terms of evaluating the hose-reel irrigators. The greatest variability of the results was showed by CUH and C_{ws} values in comparison to other results and thus these are not recommended for performance quality assessment of hose-reel irrigators. On the other hand, since the results did not show any significant difference between the values ($P > 0.05$, $F = 1.13 < F_{crit}$),

Fig. 3 Results of different uniformity (a) and non-uniformity (b) coefficients for all experimental fields
 a_r – uniformity coefficient according to Oehler; CUH – uniformity coefficient according to Heerman and Hein; CU – non-uniformity coefficient according to Christiansen; C_{ws} – unevenness coefficient according to Wilcox and Swales; γ_r – Voight uniformity coefficient; a – non-uniformity coefficient according to Oehler; Cv – coefficient of variation; E_f – degree of non-uniformity according to Hofmeister; γ – Voight coefficient of non-uniformity

Voight coefficient γ_r together with CU and spray uniformity value a_r are highly recommendable for use. In one case, the spray uniformity value did not exceed 80%, while, according to the minimum standard set, neither machine meets the required performance quality.

However, it is possible to evaluate the performance quality by means of non-uniformity and thus it was decided to apply four possible ways of evaluation and following methods were selected as guidelines: the performance quality results according to Oehler (1933); the variation coefficient and the degree of non-uniformity according to Hofmeister (1961), and the non-uniformity coefficient according to Voight (1962).

Considering the assessment of both uniformity and non-uniformity, it was opted for utilization of the non-uniformity coefficients on one hand and field conditions combined with a particular hose-reel irrigator on the other hand. In both cases, the results showed a statistical dependence, in which the achieved P -value reached $P = 0.031$ ($P < 0.05$) with $F = 3.48$ ($F > F_{crit}$) for non-uniformity coefficients and the values reached the level of $P = 0.00035$ ($P < 0.05$) with $F = 6.97$ ($F > F_{crit}$) for different input conditions (different irrigators).

For various irrigation systems, several coefficients for examination of performance quality and irrigation dose distribution uniformity have been developed over the last few decades. In case presented, as well as in case of other researchers (e.g. province in Kurdistan), the results confirmed that it is not possible to use a single achieved result as a guide for a variety of conditions, since the results depend on field conditions (Maroufpoor et al., 2010; Jobbágy and Krištof, 2018; Berbe and Mateos, 2014). Traditionally, spray uniformity evaluation method according to Christiansen is the most frequently utilized (Li et al., 2015; Lovarelli et al., 2016) for assessment of performance quality of hose-reel irrigators. Due to the application of supplemental irrigation in fields with crops with higher need of irrigation, farmers must consider the irrigation rate, which also includes drainage losses. Application of irrigation dose often results in the highest performance quality (Castellanos et al., 2016). By applying a more efficient irrigation machine, a higher performance quality can be achieved; therefore, manufacturers using less efficient systems with a given

amount of water should implement more efficient systems with higher performance quality and lower overall water consumption (Jobbágy, 2011).

The performance quality was observed in the solid set sprinkler system, in which the operating pressures were changed. Output included not only performance quality in terms of spray uniformity evaluation but also barley yield. For each input setting, the coefficient of uniformity (CU), distribution uniformity (DU), and coefficient of variation (CV) parameters were determined. The results showed higher CU values in all cases, increased by higher operating pressure (El-Wahed et al., 2016). Numerous authors (González Perea et al., 2014; Tomášik and Jobbágy, 2013) have also developed programs for assessing the quality of irrigation techniques resulting in spray uniformity coefficients after providing input values. The additional irrigation dose represents a significant energy cost in case of unforeseen phenomena. However, a detailed analysis of water distribution and irrigation systems at fields is necessary before the introduction of measures.

Conclusion

In order to evaluate the performance quality of seven selected irrigation machines, it was decided to analyse the situations on the basis of the spray uniformity and non-uniformity coefficients. The results were evaluated utilizing ANOVA statistical apparatus with a significance value ($p = 0.05$). To evaluate the spray uniformity coefficients, it was concluded that there is a statistically significant difference between the individual calculation methods with a value of $F = 6.41$ ($F > F_{crit}$). The same result was shown in the evaluation of the results depending on field conditions $F = 7.08$ ($F > F_{crit}$). On the basis of comparison of the results obtained in terms of dependence on field conditions (for non-uniformity), it was observed that the results were statistically significant with $F = 6.97$ ($F > F_{crit}$). When estimating the results based on the evaluation of dependence on calculation methodology, it was found that they show a statistically significant dependence with $F = 3.48$ ($F > F_{crit}$). Finally, study results showed that coefficients should be selected with caution according to the proposed methodologies, recommendations and standards in order to assess the performance quality.

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