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Full Length Research Paper

Water distribution uniformity of the traveling rain gun

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An experimental method combined with a computer simulation technique, specified for optimizing the water distribution of a traveling rain gun system is presented in the paper. For given operational pressure and flat terrain, this method enables accurate evaluation of track overlapping and carriage velocity of the traveling rain gun that guarantee uniform water distribution at desired water deposit level. The evaluation criteria for water deposit quality have been formulated: minimum standard deviation, skewness factor as close to zero as possible and the highest possible flatness factor. It is verified that tested rain gun system achieves the uniform water distribution of 20.36 mm in lateral direction at track overlapping of 58%. The simple accurate formula specified for carriage velocity correction is also presented.

Key words: Traveling rain gun, water deposition, track overlapping, carriage velocity, descriptive statistics.

INTRODUCTION

Land and waters in the world are under increasing pressure from the continuous growth in demand for many different purposes including irrigation (Opricović, 2009). In addition, as human activities increase, river's water quality is degraded by changes in the land cover patterns on their watersheds (Sliva and Williams, 2001; Ngoye and Machiwa, 2004; Jabbarian and Nakane 2009); what imposes the additional complexity of problems related to irrigation. However, modern competitive agriculture can not survive without irrigation and this was the main motive for engineers worldwide to study problems in this area (Miodragović, 2009). The purpose of irrigation is to provide sufficient water quantity, air, heat, micro biological and mineral soil conditions necessary for creating optimum plant growing conditions, which enable obtaining high and stable yields under any kind of expected weather conditions (Kresović, 2002). To sustain agricultural production in the coming years, it is important to optimize irrigation systems adjusting water application to crop water requirements. This will help protect both the quantitative and qualitative aspects of water conservation (Delirhasannia et al., 2010). Although, irrigation increases the yield (Al-Mefleh and Tadros, 2010); it may also generate significant expenses (Tanasescu and Paltineanu, 2004). To decrease overall crop production costs, but also to provide better conditions for achieving the sustainability of agricultural production, losses in water distribution networks have to be carefully evaluated and minimized (Sourell and Muller, 2003;Tabesh et al., 2009). The crop water use efficiency has been shown to depend on irrigation amount and frequency. Tillage practices can also influence the water use efficiency for a given irrigation frequency (Adekalu, 2006). The irrigation number, amount and uniformity of water application are used mainly to determine the efficiency of irrigation scheduling. Excessive doses of infrequently applied water will lead to high percolation losses.

A possible approach, among many others, is to develop irrigation systems characterized by the water deposit distribution as evenly as possible (Sourell and Sommer, 2000). Furthermore, starting from the water–yield relationship (Oktem et al., 2003; Dagdelen et al., 2006; Payero et al., 2006; Kiziloglu et al., 2009), an optimal time schedule of irrigation water quantity has to be established using various optimization criteria and

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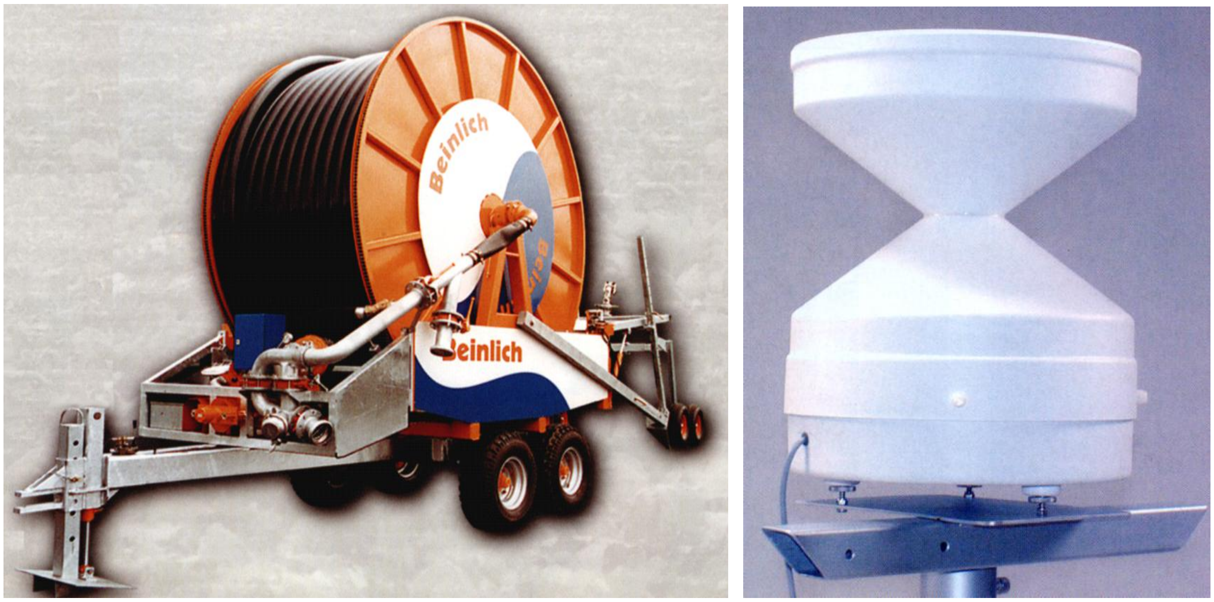


Figure 1. A traveling rain gun and rain-meter.

methods (Kuol and Liu, 2003; Lohani et al., 2004; Sahoo et al., 2006). Wigginton and Raine (2001) reported inappropriate uniformity of water distribution provided by traveling rain guns, which varied in extremely wide range: from 1% and up to 88% of nominal value, having average value of 62%. In addition, only two of eight tested machines achieved water deposition uniformity over 80%. Smith et al. (2008) have developed special simulation software which provides useful information on the water deposition uniformity of a rain gun depending on wind velocity and direction. They stated that simulation enables evaluation of raining tracks distance and concluded that water deposition between two tracks varies between 0 and 39.5 mm. In their experiment, they used data obtained from several stationary rain-meters placed on every 5 m along the rain-gun width. The data were collected for different wind speeds varying from 0.68 to 3.66 m/s. To meet specific requirements of different crops, climate and soil conditions, as well as the applied growing technology, different types of irrigation systems have been developed and applied (Dragović, 2000). Although, some sophisticated and highly economical techniques like surface and subsurface drip irrigation systems have been designed during the past few decades (Ayars et al., 2001; Hanson and May, 2004; Barragan and Wu, 2005; Kalfountzos et al., 2007); classic mobile sprinkler irrigation systems still have dominant role in vegetable and crop production. Among them, a traveling rain gun represents a possible farmers' choice for mechanized irrigation (Miodragović, 2001).

Most irrigation systems are suitable for the rectangular and square irrigation surface. The system adaptability depends on the type of irrigation system movement, construction flexibility and the number of sprinklers. Traveling rain gun is very flexible in comparison to the center pivot irrigation device. Utilization of the irrigation surface with these systems is 60% (Miodragović, 2009), but it can be decreased if the shape of the irrigated field is more different than the square. However, as it is also the case with other irrigation systems, the use of traveling rain gun is commonly followed by many problems related to optimum choice of the rain gun model and type, adequate adjustment of working parameters and maintenance, efficient control, continual monitoring etc. In general, an irrigation system should provide uniform water deposition in the longitudinal and lateral direction, equal to irrigation norm, defined for each specific period over a year. In this study, lateral and longitudinal water distribution of the traveling rain gun irrigation system is analyzed. The optimal overlapping of the irrigated tracks is found to be 58% which results in the best uniformity of water deposition of the system. However, this degree of overlapping resulted in increased water deposit which is corrected by proportional increase of the carriage velocity of the rain gun.

MATERIALS AND METHODS

Uniformity of water distribution of the traveling rain gun is analyzed in this paper. It has been applied and tested in the corn, green beans and potato production at "PKB - 7 Juli, Jakovo" farm at Belgrade south-west outer region (WGS84 44° 47′ 21″ N, 20° 16′ 29″ E). The soil type at experimental filed is Humic Gleysol. During the experiment, water distribution, system velocity and working time efficiency were determined. Water deposit and distribution were measured with the common Eijkelkamp rain-meter devices (Figure 1). For the purpose of water distribution, uniformity analysis of twelve rain-meters were placed on the 5 m distance on each of the ten measuring tracks (Figure 2), giving 120 measuring

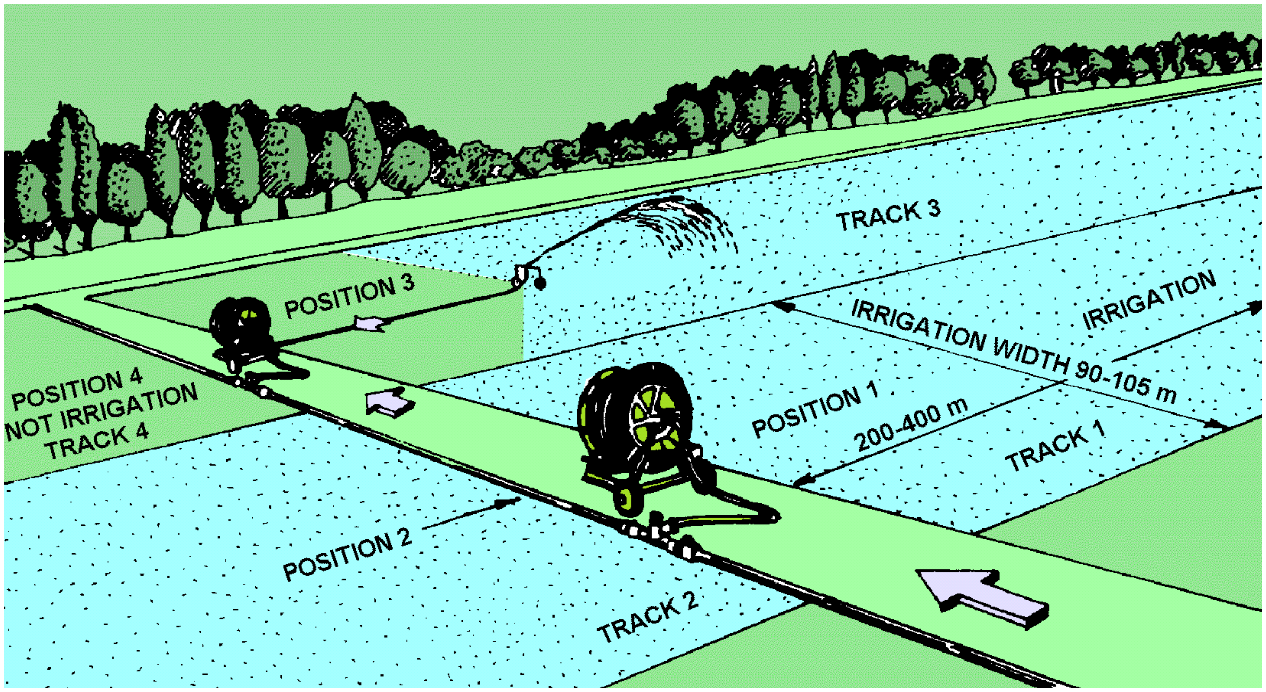


Figure 2. Irrigation scheme of the traveling rain gun.

points in total. In this way, the total of 600 m experimental field width was covered (Smith et al., 2008). The water deposit was, in that sense, measured on every 100% / 12 = 8.33% ± 4.165% of the track width and the resolution of the simulation program for optimization of the track overlapping was defined. For the purpose of the simulation lateral distribution of water deposit for the different track overlapping of a traveling rain gun system was analyzed. The algorithm is realized in MS EXCEL. Device control unit is set to water deposit of H = 20 mm for no-overlapping case. Tested overlapping levels were 0.00, 8.33, 16.67, 25, 33.33, 42.67, 50.00, 58.33, 66.67, 75.00, 83.33, 91.67 and 100.00%. The field translation velocity of the tested system was 18.65 m h^{-1}, while time efficiency coefficient was 0.86 to 0.93. The system had 350 m long PE tube, 90 mm in diameter, with the operating pressure of 4 to 10 bars. Sprinkler nozzle diameters were 20, 22.6, 25.1 and 27.6 mm.

The accuracy of water deposit distribution is evaluated by common descriptive statistical parameters. The basic water deposit distribution parameter is represented by the arithmetic mean:

$$\overline{H}=\frac{1}{n}\times\sum_{i=1}^{n}H_i \quad (1)$$

While the data dispersion around the mean is characterized by standard deviation (or the so-called root-mean-square - RMS):

$$\sigma_H=\sqrt{\frac{1}{n}\times\sum_{i=1}^{n}\left(H_i-\overline{H}\right)^2} \quad (2)$$

In the case of uniform water deposition, standard deviation is zero. Therefore, during computer simulation, track overlapping has to be chosen in a way to provide as lower standard deviation as possible.

Additional characterization factors of a distribution shape, skewness factor which represents a measure of distribution symmetry, and flatness factor which characterizes a distinction between a narrow, normal and flat distribution:

$$S_H=\frac{\frac{1}{n}\times\sum_{i=1}^{n}\left(H_i-\overline{H}\right)^3}{\sigma_H^3} \quad (3)$$

$$F_H=\frac{\frac{1}{n}\times\sum_{i=1}^{n}\left(H_i-\overline{H}\right)^4}{\sigma_H^4} \quad (4)$$

are also used. In formulas (1) to (4), *n* is the total data number of measuring points. For the symmetrical function, S_H is equal to zero. Therefore, the closer the value of S_H to zero results in the more symmetrical distribution. Furthermore, increased values of flatness F_H factor correspond to more uniform (that is, more flattened) distribution of parameter of interest. In this way, the evaluation criteria for water deposit quality have been formulated: minimum standard deviation, skewness factor as close to zero as possible and the highest possible flatness factor.

RESULTS AND DISCUSSION

After the data processing and determination of the chosen evaluation criteria for the uniformity water distribution, uniformity of lateral water deposit for the different overlapping regimes was determined (Figure 3).

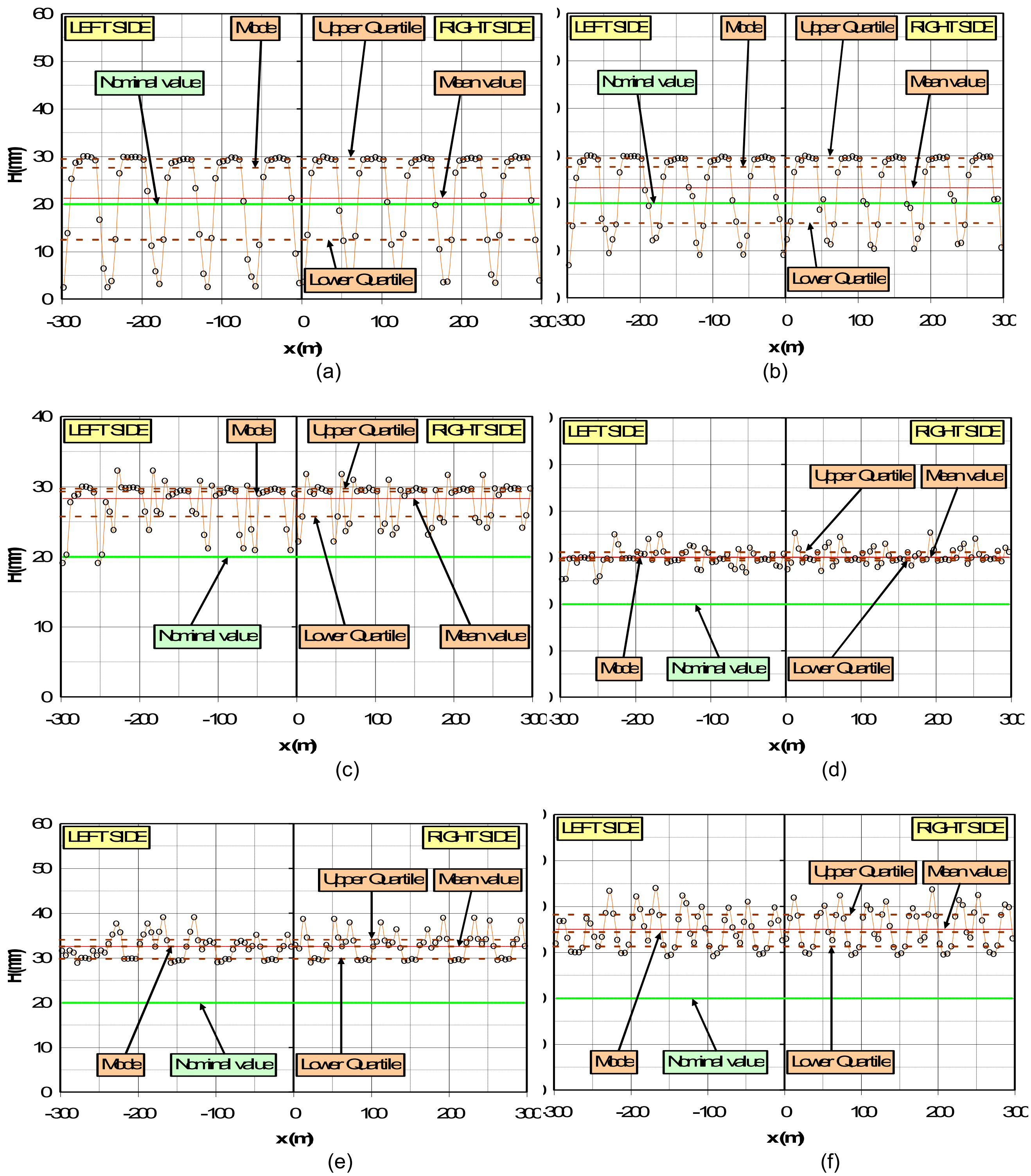


Figure 3. Lateral distribution of water deposit H (mm) achieved by the traveling rain gun at different track overlapping ratios and specified nominal water deposit of H (mm) – Part 1: (a) 0.00% overlap; (b) 25.00% overlap; (c) 50.00% overlap; (d) 58.33% overlap; (e) 66.67% overlap; and (f) 75.00% overlap.

The diagrams give data obtained from the 120 measuring points and their descriptive statistics. The “mode” value is the value where 50% of the data are above it and 50% of the obtained are below it. “Upper quartile” represents the value where 25% of the data obtained are above the given irrigation rate while “lower quartile” represent the

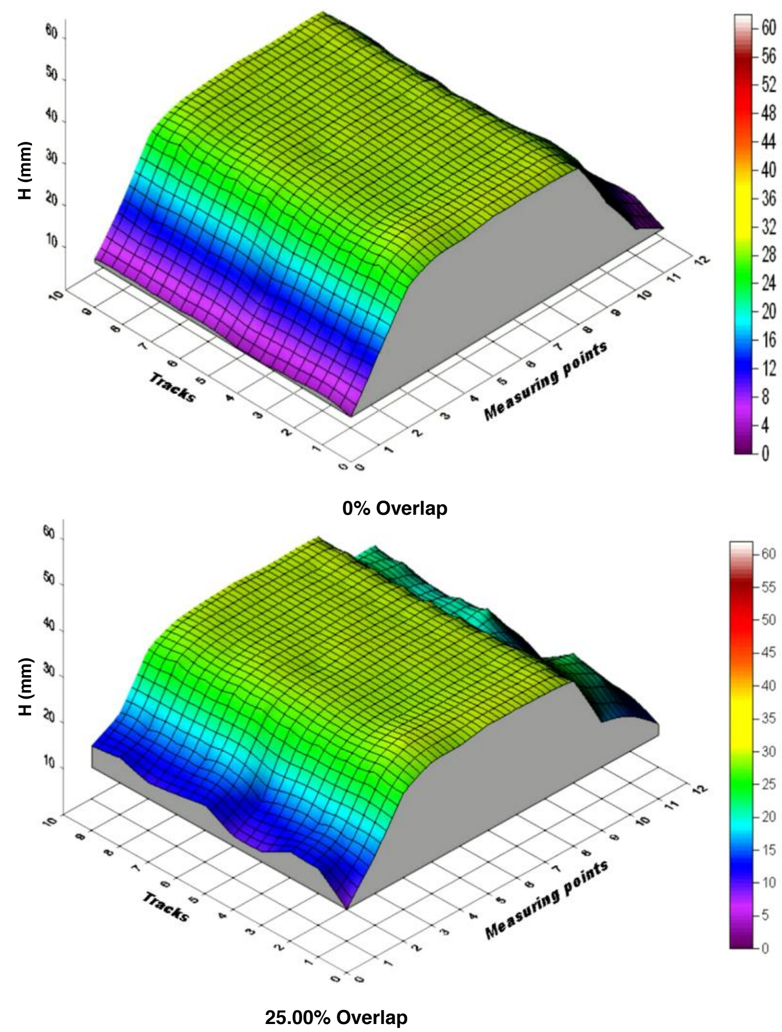


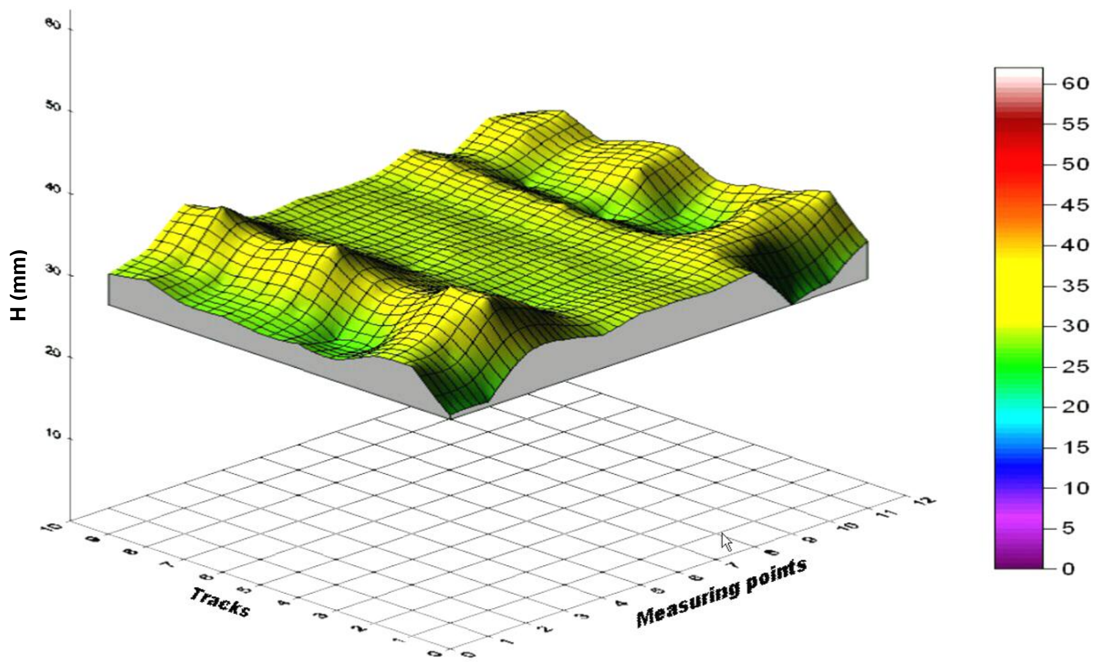
Figure 4a. Surface (left-side) and topographic (right-side) maps of water deposition H (mm) at 0 and 25% track overlapping - Part 1.

value where 25% of the obtained data are below the given irrigation rate. It can be seen from the diagrams that the water distribution along the rain-gun irrigation system is not uniform and that it highly depend on the track overlapping. If there is no overlapping (0.00%), the water distribution is very un-uniform and it varies in range of 2.5 to 30 mm. Compared to the nominal value, these oscillations are considerable. When overlapping is increased to 25% (Figure 3b), these oscillations are in the range of 10 to 30 mm which is still a considerable difference regarding the nominal value of 20 mm. When the overlapping is increased to 50%, it can be seen that all values for irrigation rate are higher than the nominal value and that uniformity of water distribution along the system is better. The variations are in range of 19 and 32 mm (Figure 3c). Finally, when the overlapping is set to 58.33%, all the values are tightly concentrated around the mean value, giving the good uniformity of distribution. It is obvious that the tracks overlapping increases the water quantity provided by the irrigation system. Thus, for the ordinary setting of nominal value equal to 20 mm, the mean water deposit was 30.1 mm at optimal overlapping of 58.33%.

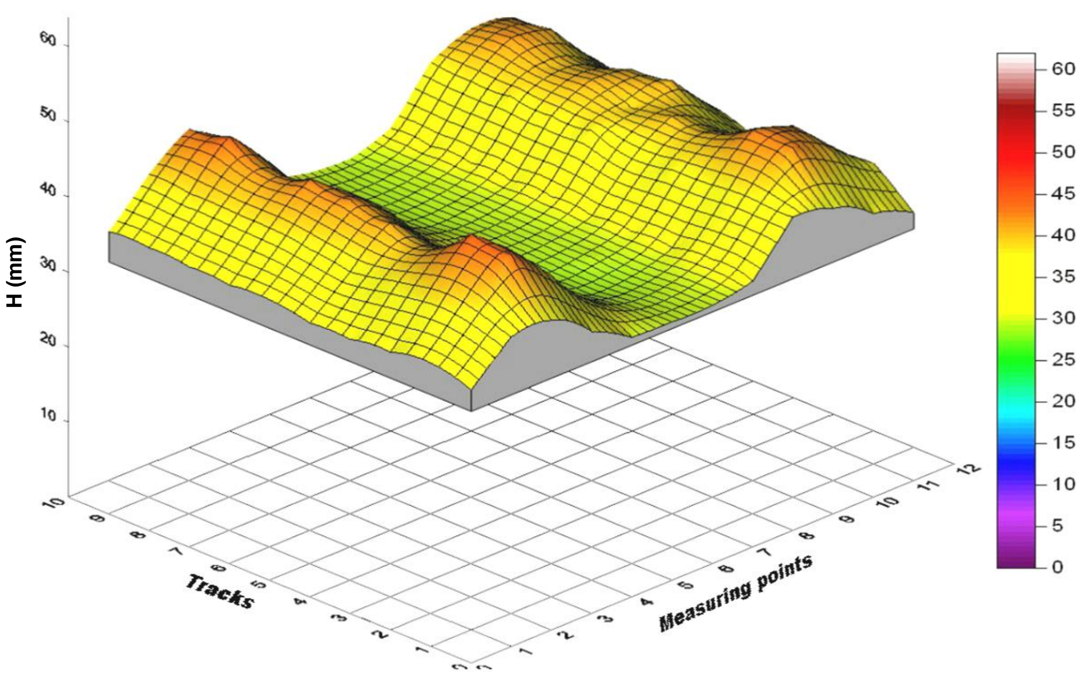
In the experimentally tested case, assuming tracks no-overlapping (0.00%), the mean water deposit of 21.2 mm was fairly close to the nominal value. Furthermore, track overlapping proportionally increases the time needed to perform the operation. To accomplish the solution of this problem, the translation velocity of the device has to be increased, according to the formula:

$$v_{58.33\%} = v_{0.00\%}\ H_{58.33\%} / H_{0.00\%} = 18.65\ \text{m h}^{-1}\ 30.1\ \text{mm} / 20\ \text{mm} = 28.7\ \text{m h}^{-1} \quad (5)$$

In this way instead of 18.65 m h^{-1}, the translation velocity of 28.07 m h^{-1} will provide uniform water deposition close to the nominal value. The time needed for this operation will be equal in both cases. In order to illustrate the problem, 3D presentations of water deposition, as a function of track–overlapping at standard translation velocity of 18.65 m h^{-1}, are presented in Figure 4.



58.33% Overlap



75.00% Overlap

Figure 4b. Surface (left-side) and topographic (right-side) maps of water deposition H (mm) at 58.83 and 75.00% track overlapping - Part 2.

Figure 5a presents basic statistical parameters of water distributions achieved at different track overlapping at nominal experimental velocity of 18.65 m h^{-1}. If translation velocity of the traveling irrigation device is optimized, that is, optimally increased according to the Equation 5, the adequate change of water deposit H to optimal value is achieved, as it is presented in Figure 5b. However, the most accurate and reliable representation of the uniformity of water deposition is given in Figure 5c and d. They present the standard deviation σ_H (mm), skewness

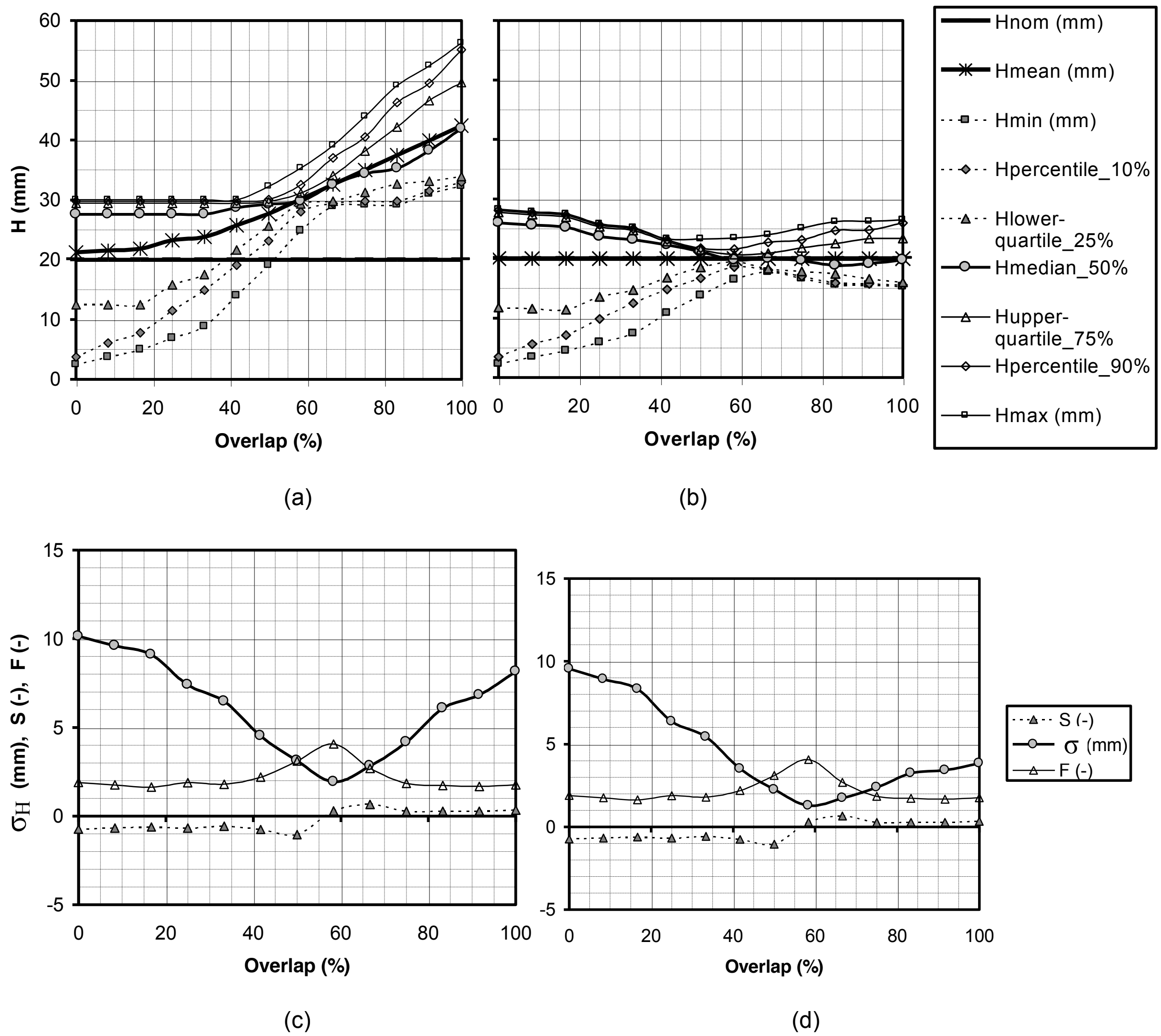


Figure 5. Water distribution of a traveling rain gun: (a) basic descriptive statistical parameters at experimentally set-up velocity of 18.65 m s^{-1}, (b) basic descriptive statistical parameters at optimized velocity of 28.7 m s^{-1} (following Equation 1), (c) standard deviation, skewness and flatness factor at experimentally set-up velocity of 18.65 m h^{-1} and (d) standard deviation, skewness and flatness factor at optimized velocity of 28.7 m s^{-1} (following Equation 1).

S_H (-) and flatness F_H (-) factors of water deposit distribution H (mm). The first two parameters are independent of translation velocity of rain gun device, what is their important advantage in comparison to other basic parameters like the mean value of water deposit $\overline{H}$ (mm), minimum H_{min} (mm) and maximum value H_{max} (mm), as well as the percentiles $H_{percentile\_10\%}$ and $H_{percentile\_90\%}$, quartiles $H_{lower\text{-}quartiles\_25\%}$ and $H_{upper\text{-}quartiles\_75\%}$ and median $H_{median\_50\%}$. The skewness factor has value of 0.28, closest to zero, which corresponds to symmetrical distribution at overlapping of 58.33%. In addition, at this overlapping level, the flatness factor has the higher value of 4.07 which corresponds to the most flattened water distribution H (mm). Finally, at 58.33% overlapping and non-optimized velocity, the standard deviation is the lowest, 1.93 mm. In the case without overlapping, standard deviation is even 10.14 mm. The analogue situation emerged after optimizing the translation velocity: the standard deviation is the smallest, 1.28 mm at overlapping of 58.33%, again. Without overlapping, its value is 9.56 mm (Figure 5d). In order to confirm the results of the given approach, an additional field experiment at the same location was carried out.

Track overlapping was set to 58.33%, while the gun velocity was 28.7 m/h. As it can be seen in Figure 6, measured data of water deposit are highly concentrated around the nominal value of 20 mm. Consequently, the mean value of these data (20.36 mm) is nearly identical to the nominal water deposit of 20 mm (Figure 6). This verification experiment included five repetitions. Results show that the mean value of water deposit was within the limits of 20 ± 2 mm (that is, the resulting accuracy was

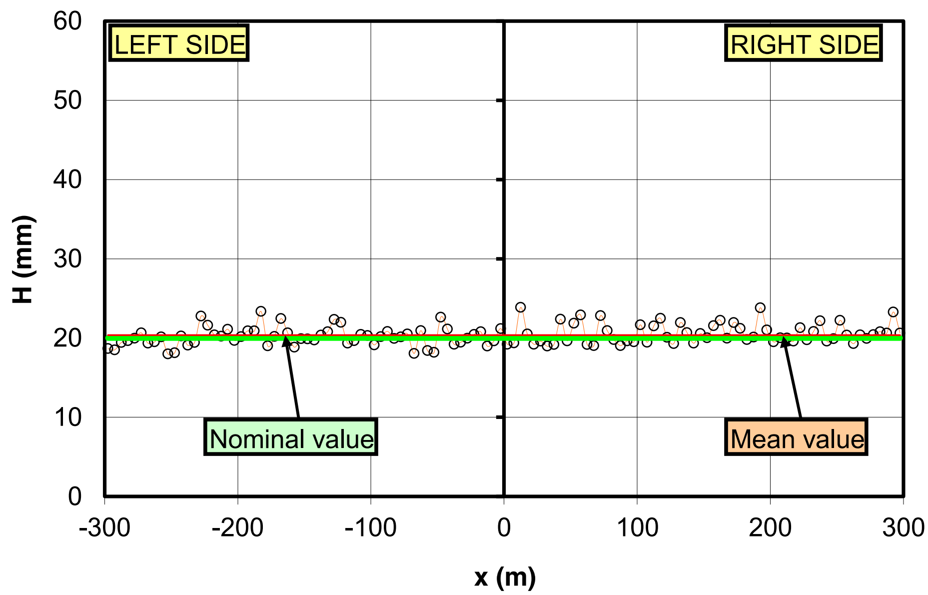


Figure 6. The uniformity of water distribution at 58.33% track overlapping and appropriate translation velocity of traveling rain gun.

within ±10%) in these tests. This way the presented approach of defining the optimal track overlapping and appropriate rain-gun translation velocity has been experimentally verified. As it can be seen, the presented model can be used for analyzing the track overlapping effect on the uniformity of distribution. It can be used for more precise water irrigation management in the filed. With the defined overlapping and the operating speed adjusted accordingly, good uniformity of distribution is achieved as well as given nominal irrigation rate. In this way, applying this simple method, energy, ecology and economy aspects of the irrigation can be improved. Uniformity of water deposit distribution is one of the most important factors that influence the quality of the irrigation system performance, that is, ecology (uniform soil watering, plants responding), economy (time of harvesting and yield) and energy stable production with higher yields and better energy utilization).

Conclusion

This work presents results of the traveling rain gun testing and examination performed during 2009. Water distribution of the tested system was non-uniform under common operational conditions. Under conditions without track overlapping, the level of water deposit varied from 9 to 30 mm and the standard deviation was 10.14 mm. In order to improve the efficiency of irrigation, the computer simulation method based on descriptive statistical parameters of water deposit distribution (the mean value, standard deviation, skewness and flatness factor) is applied. The best uniformity achieved at 58.33% track overlapping resulted in the lowest value of standard deviation, 1.93 mm only. However, in this case, the water deposit reached value of 30.1 mm which is nearly 50% higher according to the specified nominal value for water deposit (20 mm). Fortunately, this problem can be successfully solved with a built-in variator which enabled increasing the system velocity from current 18.65 to 28.07 m h^{-1}. After this correction of traveling velocity, the mean level of water deposit was equal to nominal, 20 mm, while the standard (RMS) value was even lower, 1.28 mm. Besides the mean and RMS value, two additional criteria for estimating the distribution uniformity were also used: the skewness S_H and the flatness factor F_H. At optimal track overlapping, 58.33% in tested case, the skewness factor had the value of 0.28, closest to zero value that corresponds to ideally symmetrical distribution. In addition, at this overlapping level, the flatness factor had the higher value of 4.07, which corresponds to the most flattened water deposit H (mm) distribution function. It is well known in statistical theory that these two factors are of higher-order in comparison to the mean $\overline{H}$ (mm) and RMS δ_H (mm) values, and therefore are more sensitive according to the changes of shape and uniformity of statistical distribution of interest. Thus, they represent additional parameters that are very useful in estimating its uniformity.

The additional advantage of the latter two parameters lies in their non-sensitivity on the traveling velocity of a rain gun. In other words, they have the same values which are independent of velocity of the irrigation device. However, the simulation method still posses a limitation being suitable for still air. Further studies will include tests and models that are less sensitive according to disturbances caused by wind.

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