APPLICATION AND EFFICIENCY OF MICRO SPRINKLER IRRIGATION

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In the presented paper, we evaluated the quality of work and the economics of use of irrigation system consisting of micro-sprinklers. The experiment took place on the football field in countryside of southwest Slovakia. The original irrigation system was replaced with a modern one, using a control unit, rainfall sensor, in-ground distribution pipes and micro-sprinklers. The irrigation system consisted of components forming the main and detailed irrigation equipment for irrigating an area of 4,272 m^2. The water source was a drilled well with a depth of 80 m. Detailed irrigation equipment consisted of sector micro sprinklers of two types. We monitored 13 rotary micro-sprinklers on the given playground in total. During the measurements, we proceeded according to the international standard ISO 7749-2, while the rain measuring containers were distributed into eight beams. The value of the quality of the work of individual sprinklers, expressed by the coefficient of uniformity of spraying, reached a maximum of 78.18%, but with total coverage it was higher than 90%. Anova statistical analysis did not show a significant dependence of the quality of work on the type of micro-sprinkler (for micro-sprinklers A1, A2 A3: $F = 2.95$, $P > 0.05$; for micro-sprinklers B, C: $F = 0.35$, $P > 0.05$). From the viewpoint of evaluating the economic return, the investment proved to return within the period of 4.2 years.

Keywords: micro-sprinkler, quality of work, irrigation, efficiency

Introduction

Irrigation represents a melioration measure that ensures the soil is irrigated as well as vegetation, or ground layer of air (Jobbágy, 2011). Irrigation is used also in non-agricultural applications, i.e. to irrigate parks, ornamental gardens, and public greenery, or on sports fields (irrigation of lawns and playgrounds), when growing flowers, in fruit and forest nurseries, etc. (Rehák et al., 2015). Irrigation with use of micro-sprinklers is often a difficult task, especially when the entire area must be irrigated only with micro-sprinklers (Mikropostrek 1, 2014). Available micros-sprinklers can be of different designs, while e.g. the rotary micro-sprinkler creates a concentrated, finely dispersed stream of water with the possibility of setting the trajectory of the water stream. There is a wide variety of rotary sprinklers with nozzle sets on the market (this comes with different pressure and flow requirements in the irrigation system). However, the source of water based on the irrigation method, must have sufficient capacity with a minimum working pressure of 0.25 MPa (Mikropostrek 2, 2017). The central part of the sprinkler can be extended by 10 to 15 cm, depending on the design. Smooth rotary movement of the central part is provided by an encapsulated gear mechanism (Rotačné postrekovače, 2016). The automated irrigation system enables regular and uniform irrigation, saves time and contributes to the improvement of the quality of greenery and thus also increases its aesthetic appearance. Modern irrigation systems allow almost unlimited possibilities of irrigating areas of different shapes, different subdivisions and different requirements for irrigation (Závlaha, 2017).

When evaluating the efficiency of the operation of technology at the firm level, we usually use a certain set of indicators, which consists of two groups. The first group are operational indicators characterizing the use of technology. The main indicators in this group are the machine operating hours, or the overall performance of the machine set. The second important group of indicators are the so-called cost indicators (Ďuďák, 2016). These cost indicators enable to evaluate the overall sum invested into technology.

The main aim of presented article is to deploy a modern irrigation system, evaluate its quality of work and investment efficiency of operation.

Material and methods

Initial state

In the initial phase, the football field was irrigated with a shock sprinkler placed on the running gear with wheels. The football field was equipped with two sampling points with a 2″ ball valve and a quick-coupling flange for connecting a 2″ type B hose. The sprinkler worked at a pressure of 0.4 MPa. A hose was connected to the sprinkler with quick coupling. A nozzle with a diameter of 10 mm was placed on the given sprinkler. The sprinkler flow was 9.3 m^3.h^{-1}. The working dribble of the given type of sprayer was 20 m. Irrigation of the football field required eight working positions of the sprinkler, while the time period of the irrigation dose at one position was 30 min. It follows from the obtained source materials, that 37.2 m^3 of water was consumed for one irrigation of the playground.

Modernization of field irrigation

The modernization of irrigation was based on replacing of components of the main and detailed irrigation equipment (Figure 1). The total area of the playground is 4,275 m^2. Water is taken from a drilled well with a depth of 80 m. Water is pushed from the well by submersible pump with a capacity of 2.2 kW through a discharge pipe and a filter into a pumping tank with a volume of 20 m^3 (equipped with surface electrodes to ensure a sufficient amount of water during irrigation). A high-pressure pump with a power of 4 kW is located in the tank, which is connected to the system automatically (operating only during irrigation). The water source object is located 154 m from the playground, and there is a pressure tank with a volume of 1,000 l (equipped with a pressure switch set to a value of 0.8 MPa, Figure 2). The water is further transported to the distributors through the control shaft through a PE pipe with a maximum pressure of up to 1 MPa and a diameter of 110 mm. The main water shut-off and a large-capacity filter with the possibility of discharging mechanical impurities are located in the shaft. The water is further transported to the sprinklers.

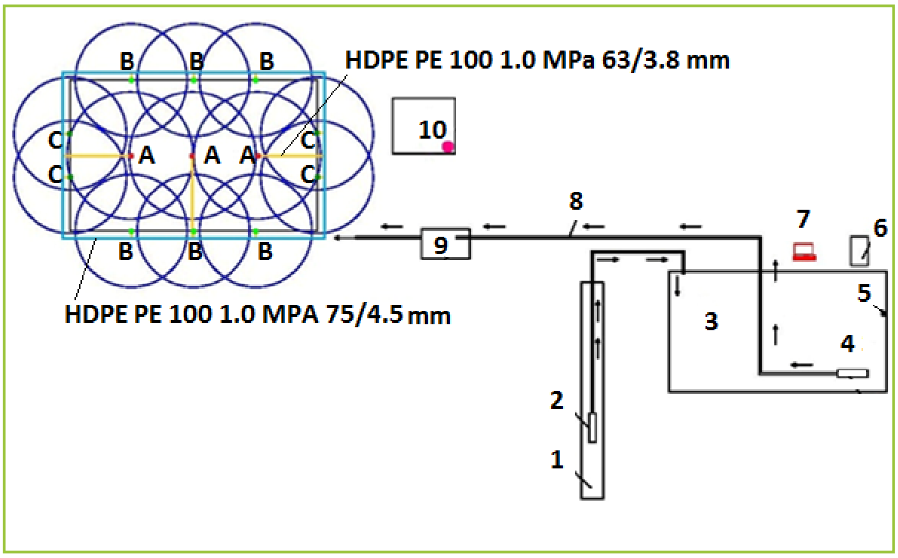

Figure 1 Irrigation system
Source: own elaboration
1 – well, 2 – submersible pump, 3 – pumping tank, 4 – submersible pump 4kW, 5 – surface electrodes, 6 – pressure tank 1000 l with pressure switch 1.2MPa, 7 – distributor, 8 – distribution of water from the pumping station reservoirs to the playground, 9 – control shaft with filter and ball valve, 10 – building with control unit, A, B, C – micro sprinklers (A – central, B – side, C – front)

The detailed irrigation device thus consists of 13 micro-sprinklers (Figure 3). Each sprinkler has a built-in solenoid valve that opens after an impulse from the control unit, which is fully automatic. The technical parameters of the sprinklers are listed in Table 1. The working pressure of the sprinklers reached an average value of 0.6 MPa.

Irrigation is controlled by a Hunter Pro-C type control unit (Figure 4), which allows to set the necessary functions for controlling individual sections (operation, time, date, program, sequences, sections, pump, manual/auto mode). To ensure high-quality irrigation, a rain sensor is connected to the control unit (Figure 4), which also serve as an insurance element.

Field measurements of work quality

The evaluation of the quality of the work of the irrigation system was carried out on the football field in the village located 13 km northwest of Nitra, Slovakia. The procedure was followed according to the ISO 7749-2 standard (Measurement of spray uniformity). The village covers an area of 15.07 km^2 at an altitude of 162 m.a.s.l. The field work procedure had to be modified with regard to the performance of the pumping station (flow ratios), while it was necessary to gradually switch individual micro-sprinklers. The measurement time was shortened to 12 minutes for practical reasons. The measurement of the uniformity of the spray was carried out by the area or radius method and was based on the distribution of precipitation measuring vessels according to the type of micro- sprinkler (Figure 5). The results are evaluated by a one-factor Anova analysis and the dependence of the quality of work on the micro-sprinkler is studied.

Economic efficiency

When deploying the modernized irrigation system, we also look at the economic side of the irrigation method compared to the initial methods. The evaluation of economic efficiency was based on the total consumption of water and electricity converted to real costs expressed in economic units. Methodological procedures are applied to determine total costs (fixed, variable

Figure 2 Pressure tank, control shaft
Source: own photograph on site

Table 1 Technical parameters of sprinklers

Parameter		Hunter G995E53P8S Side (B)	Hunter G990E53P8S Central (A)	Hunter G95E53P8S Front (C)
Recommended pressure (MPa)	MPa	0.55–0.83	0.55–0.83	0.4–0.7
Maximum pressure (MPa)	MPa	0.1	0.1	0.1
Angle of beam (°)	°	22.5	22.5	22.5
Section setting (°)	°	40 – 360	360	40 – 360
Flow (l.min^{-1})	l.min^{-1}	137–282 (197)	137–283 (195)	113–364 (145)
Extension height (cm)	cm	8	8	8
Dribble (m)	m	23.5 – 29.9	23.5 – 29.9	20.4 – 29.3
Number	pc	6	3	4

Source: own, based on source materials

Figure 3 Micro-sprinkler side and central
Source: own photograph on site

Figure 4 Control unit, rain sensor
Source: own photograph on site

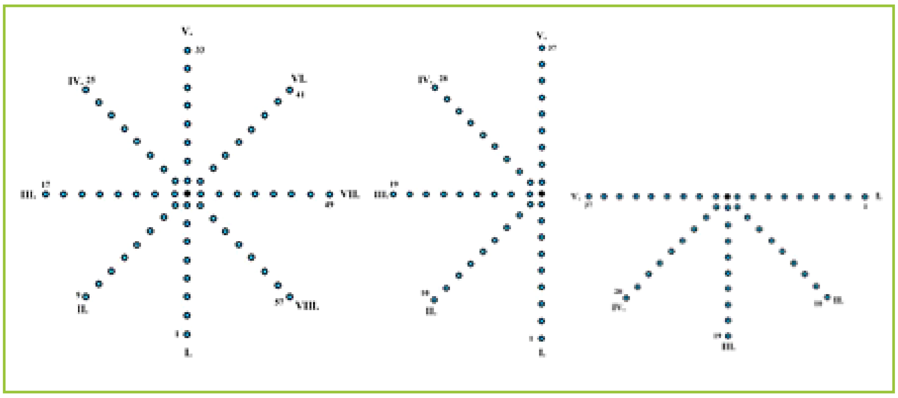

Figure 5 Positions for rain measuring vessels – central, front and side sprinkler
Source: own elaboration

and indirect costs; Ďuďák, 2016). The total direct annual irrigation costs are calculated according to the following relationship:

$$ {}_rN_{mC} = {}_rN_{mT} + {}_rN_o + {}_rN_e + {}_rN_{zp} \quad €.year^{-1} \quad (1)$$

where: ${}_rN_{mC}$ – total direct annual irrigation costs, €.year^{-1}; ${}_rN_{mS}$ – direct annual cost of irrigation system, €.year^{-1}; ${}_rN_e$ – annual energy cost €.year^{-1}; ${}_rN_o$ – annual maintainance cost €.year^{-1}; ${}_rN_{zp}$ – annual labour cost €.year^{-1}

Results and discussion

As part of the experiment, we managed to modernize the irrigation system consisting of the main and detailed irrigation equipment. The original irrigation system was replaced with a new one, and we constructed a pumping station with water distribution to individual micro-sprinklers.

Measurements of the quality of work of micro-sprinklers

As part of field measurements, we measured the quality of work of selected micro-sprinklers (Figure 6). During the experiments, we did not notice any influence of weather conditions. During the measurements, we applied the distribution of rain measuring vessels described in the methodology, while the achieved results were monitored in sequences lasting 12 minutes. Irrigation doses were converted to mm of water column.

The first tested micro-sprinkler A1 achieved a spray uniformity coefficient of 49.47% with an average irrigation dose of 1.64 mm. Graphic display of the results in the ArcGis v.9.0 program for the A1 micro-sprinkler is shown in Figure 7 from which it is clear that a substantial part of the dose was concentrated in the central part. It is obvious that deploying a micro-sprinkler requires sufficient coverage to increase the uniformity of the spray from all sides. A significantly higher value of spray uniformity was achieved with the A2 micro-sprinkler (located in the central part of the field), i.e. 70.94%. The average irrigation dose was 1.2 mm. The value of the coefficient of variation was significantly lower (39.21%) than for the A1 micro-sprinkler (59.09%). The graphical representation of the results is shown in Figure 8. When evaluating the third micro-sprinkler (A3), there was only a slight decrease in the quality of work (coefficient of uniformity CU = 70.87%), while the average value of the irrigation dose reached 1.29 mm. The difference in these two last measurements was a higher dribble value approx. by 1 m, which increased the total number of rain measuring containers to 72 pcs. Overall, it can be said that by covering the central circular micro-sprinklers almost to the middle of the field, the quality of the work clearly increases. A graphic representation of the uniformity of the spraying of the A3 sprayer is shown in Figure 9.

Further research was aimed at evaluating the uniformity of spraying of front and side micro-sprinklers. When evaluating the quality of the work of micro-sprinkler B, the maximum value of the irrigation dose was 5.45 mm. The value of the spray uniformity coefficient CU reached 78.18% with an average irrigation dose of 2.25 mm. The graphical representation of the results is shown in Figure 10. The last micro-sprinkler evaluated was the frontal type (C), which irrigated in a 180° section. The maximum irrigation dose was 6.09 mm and the spray uniformity coefficient CU reached the value of 48.89%. A graphical representation of the results of the irrigation dose is shown in Figure 11. The value of the coefficient of variation was quite high (65.86%) given the average value of the irrigation dose of 2.11 mm.

From all the graphical and statistical results it is clear that it is not possible to achieve sufficiently high value of the spray uniformity coefficient without an overlap. That is why individually achieved results were statistically modeled into a common result, while it was found that the quality of work evaluated by the spray uniformity coefficient reached a value of more than 85%. The dependence of the quality of work on the micro-sprinkler was monitored through statistical analysis (Anova). The results for the evaluation of the three central micro-sprinklers (A1, A2, A3) show that the irrigation dose and its distribution is not statistically significant (F (3.03) = 2.95, P >0.05). When evaluating the results of the irrigation doses of the side

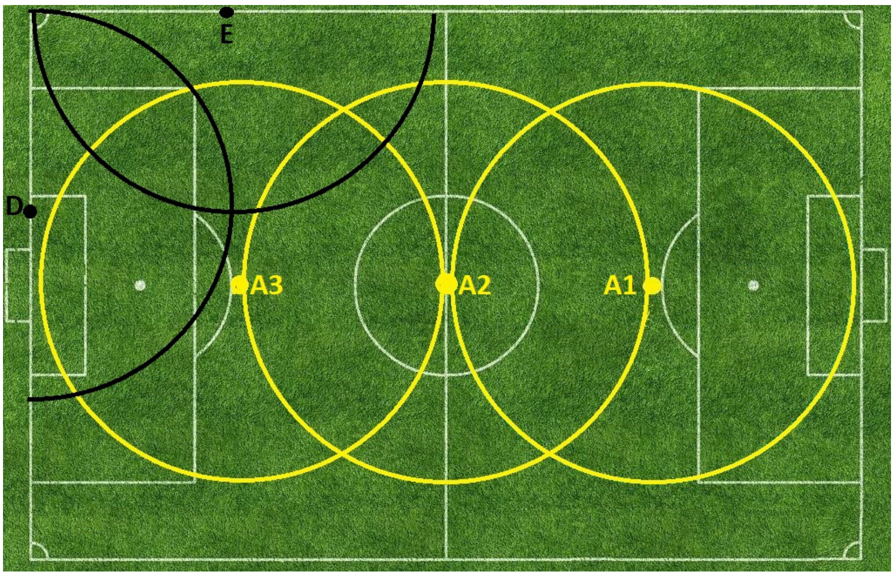

Figure 6 Positions of observed micro-sprinklers
Source: own elaboration

and frontal micro-sprinkler, we also did not confirm a statistical dependence (F (3.94) = 0.35, P >0.05).

Improved quality of work, i.e. increasing the value of the spray uniformity coefficient, can be achieved by correct setting and redistribution of pressures. In a traditional system, pressure changes due to the increasing distance between the water source and the sprinkler. The connection of the system to the loop, or the loop with the switchboard, was investigated in Babylon (KhaganVillage, Governoate, Iraq) in the period between November

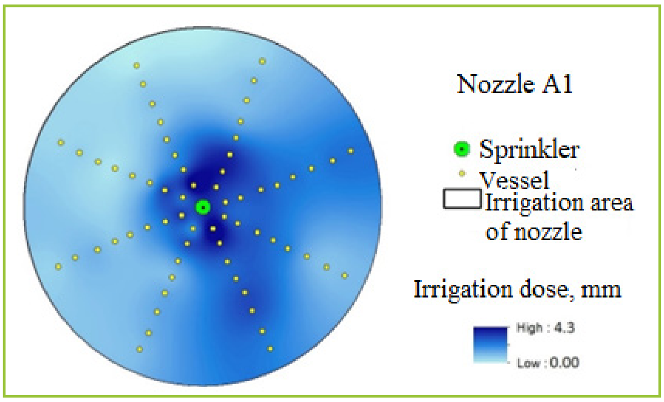

Figure 7 Irrigation dose – micro-sprinkler A1
Source: own elaboration in ArcGis v.9.0

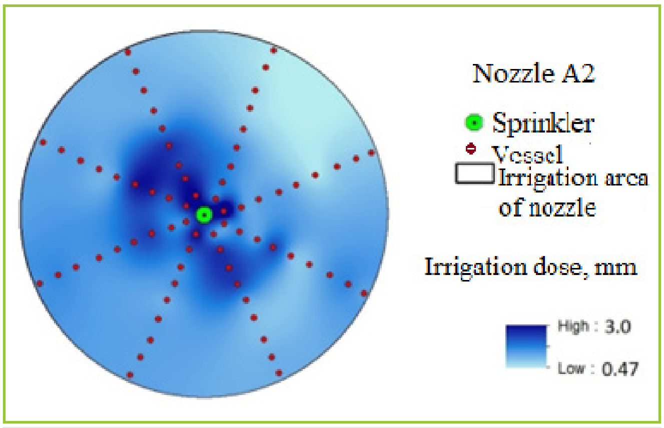

Figure 8 Irrigation dose – micro-sprinkler A2
Source: own elaboration in ArcGis v.9.0

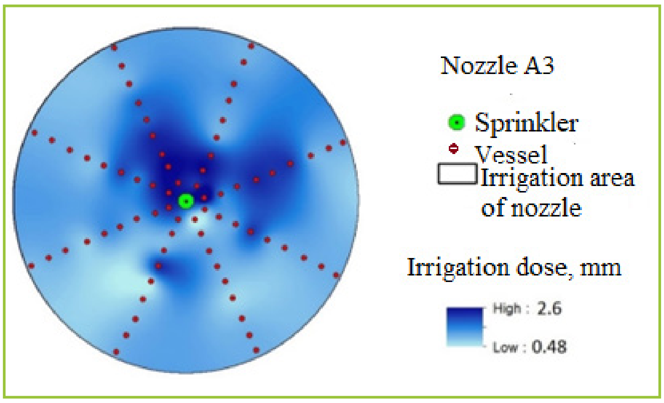

Figure 9 Irrigation dose – micro-sprinkler A3
Source: own elaboration in ArcGis v.9.0

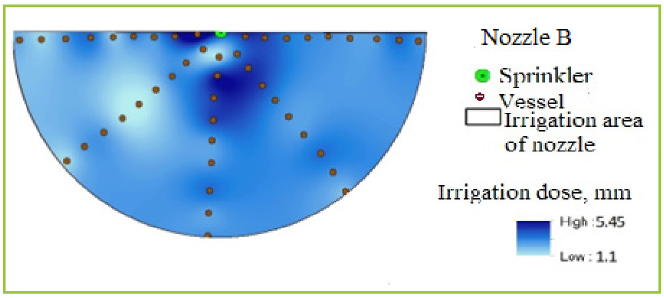

Figure 10 Irrigation dose – micro-sprinkler B
Source: own elaboration in ArcGis v.9.0

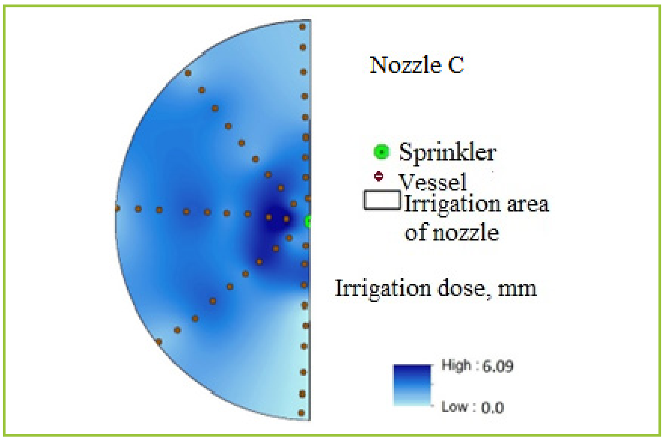

Figure 11 Irrigation dose – micro-sprinkler C
Source: own elaboration in ArcGis v.9.0

and December. The Epanet software was used to evaluate and model the results. The results showed significant changes in pressures when connecting to a classic or a loop system. On average, the value of the uniformity coefficient increased by 13.21% during practical measurement and up to 17.62% during theoretical measurement. To calculate the coefficient, they used the method according to Christiansen (UdaiAdnaid, 2013). When the coefficient of uniformity CU value is approximately 70% or higher, the measured irrigation rates in the vessels tend to follow a normal distribution. In the case when the average irrigation dose is equal to the required application dose, 50% of the irrigated area will be irrigated below average and the remaining 50% above average (or adequately irrigated). This is because the normal distribution is symmetric about the mean (Merkley, 2001). A partial modification of the equation according to Christiansen was used by the authors Maroufpoor et al. (2010) and Wilcox and Swailes (1947). The difference is that Christiansen uses the sum of deviations from the mean in the equation, and Wilcox and Swailes use the sum of squared deviations, which is then squared root.

Economic efficiency

As part of the solution to the irrigation system project, we also focused on evaluating the economic efficiency of its deployment. In this case, it was considered that the pump station built in the initial phase would cover the costs of water, which would otherwise have to be taken from the municipal water supply. The estimated price of municipal water at the time of implementation was 0.6 €.m^{-3}. The water consumption for one irrigation was 37.2 m^3 (i.e. with a 4-hour daily irrigation regime). We considered the irrigation season for the football field in a total number of 150 days, or 75 days if it is assumed to irrigate every other day. For these two options, we point

Table 2 Descriptive statistics of results and quality of work – micros-sprinklers A1, A2, A3, D, E

Parameter	A1	A2	A3	B	C
Average (mm)	1.64	1.2	1.29	2.25	2.11
Standard deviation (mm)	0.12	0.06	0.05	0.11	0.21
Minimum (mm)	0.1	0.47	0.48	1.1	0.0
Maximum (mm)	4.3	3.0	2.6	5.45	6.09
Sum (mm)	105.08	86.85	92.59	101.40	95.25
Count	64	72	72	45	45
Coefficient of variation (%)	59.09	39.21	35.03	31.34	65.86
CU (%)	49.57	70.94	70.87	78.18	48.89

Source: own processing

out the return on investments. The total cost of building the pumping station, including material (pump, switchboard, components, filter, electrical wiring, cooling cover, float, etc.), transport and work operations, amounted approx. 4,114 €. The total costs for other irrigation components (irrigation hoses, micro-sprinklers, automation and components) were approx. 8,046 €. The total costs for the implementation of irrigation were therefore estimated to be 12,160 €. Economic efficiency is demonstrable by recalculating the costs incurred on the one hand and saving water or human labor on the other. When deploying automatic irrigation and considering irrigation on a daily basis or every other day, the cost of labour needs to be considered (employee for full-time or half-time or equivalent). Estimated cost with all levies for the initial state of irrigation system would amount approx. 3,000 € (irrigation every day), or 1,500 € (every other day). The cost of water for the original method of irrigation would represent a rather significant item, especially for daily application (3,348 €), or half the value for irrigation every other day (1,674 €). In case of modernization of irrigation system, costs of water were not calculated, because underground reservoirs were used up to the value of the amount set by law. The consumption of the pumping station in the form of electricity would amount 567 € (during daily operation) or 283.5 € (operation of irrigation every other day). Considering all these parameters, it can be concluded that the return on investment would be approx. 2.1 years, and when operating every other day 4.2 years. However, we did not consider the maintenance costs of any of two systems.

As stated by Ďuďák (2016), the main economic indicators, according to which the efficiency of mechanization is evaluated, are the direct costs of the monitored operation with the application of the given machine, or machine set, and indicators of the quality of work of this machine (set) related to the performance unit.

Conclusion

As part of the implementation of the project to modernize the irrigation system of the football field in sample village, we carried out the research related to the quality of the work of micro-sprinklers. A total of five micro-sprinklers were tested, of which three were central, one side and one frontal. From the results, it can be concluded that the quality of the work was satisfactory for each individual, but for the overall evaluation, it is necessary to ensure sufficient overlap of the irrigated areas. The uniformity of the spray reaches the limits required by practice. From the point of view of the economic efficiency of the deployment of the irrigation system, the return within 4 to 5 years represents a profitable investment for the conditions of the football field. In all other years to come after these 4–5 years, the use of modernized irrigation is only profitable.

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