Evaluation of efficiency of precision irrigation for potatoes

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Abstract

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The objective of the presented paper was to verify in practice the methods of precision irrigation, defined theoretically, under the employment of reel hose irrigation machines. The surface area of the field was 22 ha. The basic soil hydrological coefficients were measured in 19 monitoring points, specifically the field capacity and the wilting point. The field capacity ranged between 28.83% and 32.11% by vol., and the wilting point was in the interval between 8.40% and 12.40% by vol. At the conclusion, the soil moisture as a factor decisive for determining the irrigation rate was measured in these monitoring points. The irrigation rate ranged from 0 to 40 mm for the specific date of the soil moisture determination. During the whole growing season, five irrigation rates were applied according to the principles of precision irrigation. As compared to conventional water application, precision irrigation contributed to water saving in the amount of 478.56 m^3/ha. The electric power saving reached 249.68 kWh/ha. The cost saving was characterised by the value of 9.1 EUR/ha and this represented 23.8%. The results have shown that precision irrigation is a fully effective system of precision farming, although the procurement and implementation of new technology and software requires at first a significant financial cost. There is also an increased need for the education and skills of the operating staff.

Keywords: precision irrigation; soil hydrological coefficients; soil moisture

As compared to conventional farming, precision farming perceives the within-field conditions in a different manner. Precision farming takes into account the fact that the field as a whole together with the soil and its properties, the content of nutrients, soil moisture, etc. represents an environment that is spatially variable (Nozdrovický et al. 2008).

Precision irrigation, as part of precision farming, is at the beginning of investigation and represents water application in a specific place and at a specific rate. That concurrently takes into account a reduction in irrigation water consumption and contributes in this way to the fulfilment of a world-wide trend resulting from the shortage of this strategic element (Sourell 2003).

The implementation of precision irrigation requires additional equipment to control the irrigation rate, information on soil properties and on the condition of a crop stand. The potential of variable rate irrigation is in the increase of the yields, quality and economic rate of return (King et al. 2006).

The use of precision irrigation is restricted by the lack of basic knowledge on spatially variable crop and soil properties. The experiments resulted in a positive assessment as regards the implementation of precision farming in the management of irrigation (Sadler et al. 2002).

Fraisse et al. (1995) simulated variable rate irrigation with a subsequent verification of the results in practice.

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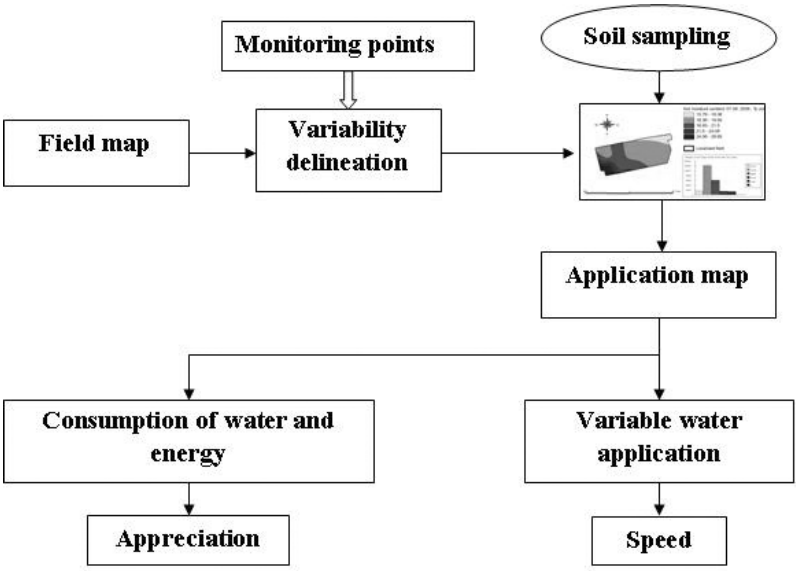

Fig. 1. Strategy of precision agriculture

Irrigation practice often uses the conventional method of irrigation. However, there are very few homogeneous fields in practice as regards the granulometric composition of soil. Therefore, a field must be divided into individual sub-units that are mutually independent in terms of the need for tillage, nutrition and irrigation (Sourell, Al-Karadsheh 2003).

Research connected with precision irrigation and soil hydrological coefficients was conducted, *inter alia*, at Idaho Agricultural Experiment Station (Kimberly, USA). The experiments were based on measuring the field capacity (25.0–44.6% by vol.), wilting point (10.0–18.4% by vol.), and available water capacity (13.9–28.4 cm/m) (King et al. 2006).

The mapping of spatial variability concerning the field capacity, wilting point, and reduced available water capacity was performed in 9 zones and subsequently used as an input parameter for the management of precision irrigation. In the first three zones was a pasture, the following three zones contained potatoes, and the last three zones contained maize. The values of the field capacity ranged between 10% and 37% by vol., those of the wilting point were in the interval between 3% and 11% by vol., and the values of reduced available water capacity ranged from 7–31% by vol. (Hedley et al. 2009).

Fig. 2. Moisture meter HH2 with Wet sensor

Based on the research conducted abroad (Federal Agricultural Research Centre FAL, Braunschweig, Germany), the lowest costs amounting to 191 EUR/ha were achieved in the case of centre pivot irrigation with the total irrigated area of around 57.6 ha. During the irrigation season, the highest costs amounting to 911 EUR/ha were obtained with stationary drip irrigation. Mobile drip irrigation fell between these extremes with the cost amounting to 267 EUR/ha (Debrala, Sourell 2002).

MATERIAL AND METHODS

The objective of the presented paper was to verify the elaborated methods of precision irrigation. The solution of the work followed the methodical procedure shown in Fig. 1. The field boundaries were determined using a hand-held GPS navigator – Garmin eMAP. The soil moisture was measured by HH2 Moisture Meter and WET Sensor (Delta-T Devices, Ltd., Cambridge, UK) (Fig. 2). The application maps were prepared after the determination of the soil moisture and soil hydrological coefficients. Irrigation was performed using reel hose irrigation machines distributed within the field. The map of spatially variable soil moisture contained the zones of delineated within-field variability.

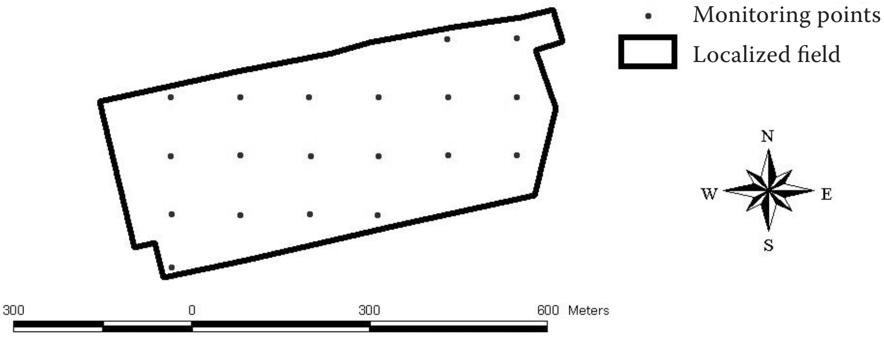

Fig. 3. Localised field and monitoring points

The tables of the irrigation schedule were produced after preparing the application map.

In conclusion, the crop yield was determined, and the use of precision irrigation was evaluated in terms of its economical benefits. The methodology suggested by the Department of Machines and Production Systems (Slovak University of Agriculture in Nitra) was used for determining the soil moisture. This methodology involves taking a crop sample from the area of 10 m^2 (in each monitoring point). The samples were placed into bags marked with a relevant numerical code.

The algorithm according to Rataj (2005) was used to determine the operating costs. This algorithm enables to change the input parameters (irrigation water requirement, tractor insurance, diesel fuel price, electrical power price, water price, hour rate for an employee and field size) that are associated with the selected field and year in which the experiment is undertaken.

In terms of law, water for irrigation is provided free of charge but the price of services for the water supply is subject to payment. In our case, the agricultural holding had its own wells and pumps. The costs were computed for such case when the entity had not obtained water subsidies.

In the case of variable rate irrigation, the value of labour costs will be increased by the value of costs incurred by the employee who changes the irrigation rate.

Annual costs for the change of irrigation rate under variable rate irrigation (this equation shall apply if the work is performed by one worker):

$$ {}_{r}N_{zm} = {}_{h}N_{zp} \times 1.352 \times {}_{r}W_{zm} \qquad (1) $$

where:

${}_{h}N_{zp}$ – hour rate of the employee for changing the irrigation rate (EUR/h)

1.352 – coefficient of insurance contributions

${}_{r}W_{zm}$ – total time of all changes in irrigation rates (h/year)

The time required for the change of the irrigation rate depends on:

- field size;
- number of irrigation machines;
- time required for one shift;
- time required for transport between irrigation machines;
- number of shifts during the whole irrigation period on all of the irrigation equipment used.

As compared to precision irrigation, conventional irrigation will show a change in the total cost. The following costs will be changed:

- variable costs per irrigation machines (higher annual employment of electric motor with the pump);
- costs of water (higher amounts of water consumed).

RESULTS AND DISCUSSION

By virtue of good experience gained over the years from cooperation, the agricultural holding Agrocoop Imeľ, Ltd. (Imeľ, Slovak Republic) was chosen for the experiments. This holding is situated in south-western Slovakia, in the district of Komárno. The area is characterised by a flat terrain, with a gradient ranging between 0° and 2°.

As regards the soil and weather patterns, the holding is classified as belonging to the maize production area. In terms of precipitation, the area can be included into arid, very dry area with an average long-term annual precipitation total of 547 mm (for the period from 1951 to 1980). The precipitation is not distributed uniformly. The average annual temperature is 9.9°C, the average temperature in the growing season is 16.6°C, and the precipitation in the growing season is 355 mm. The elevation of this area is 107–110 m a.s.l. The total area of agricultural land in this holding amounts to 1,822 ha, out of which arable land is 1,730 ha with the preponderant type of loamy sand to loamy soils. Potatoes take

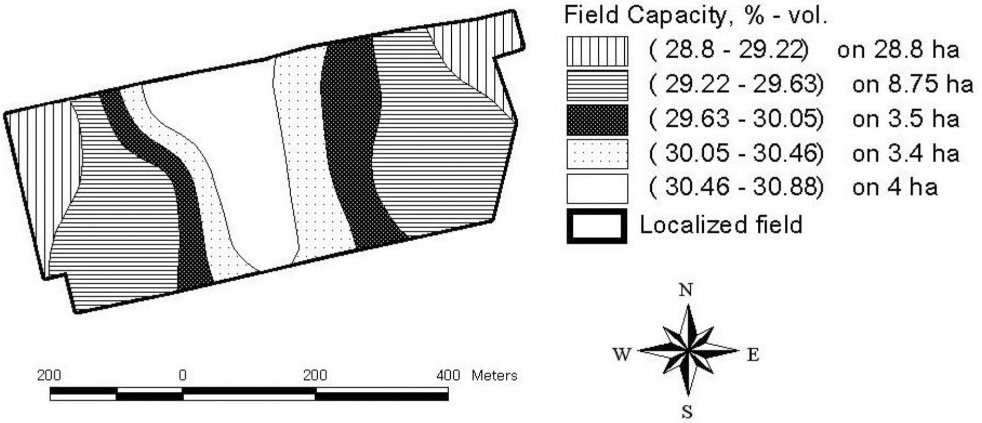

Fig. 4. Maps of field capacity

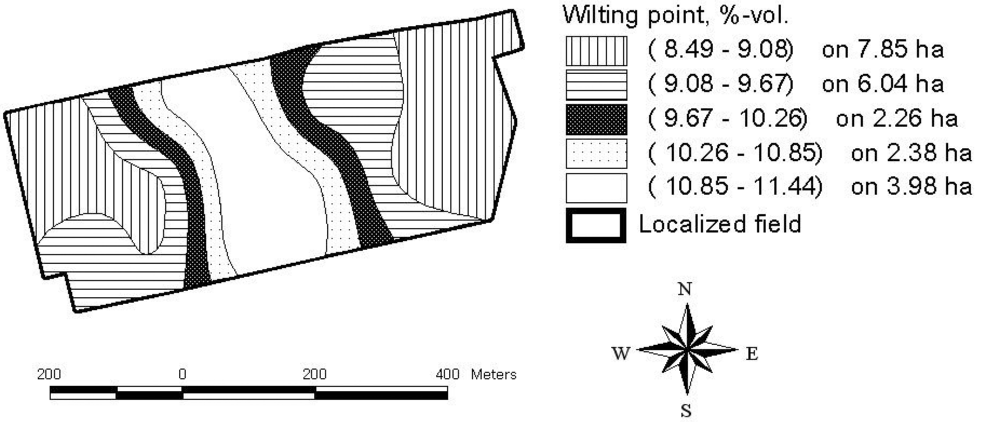

Fig. 5. Map of wilting point (BV)

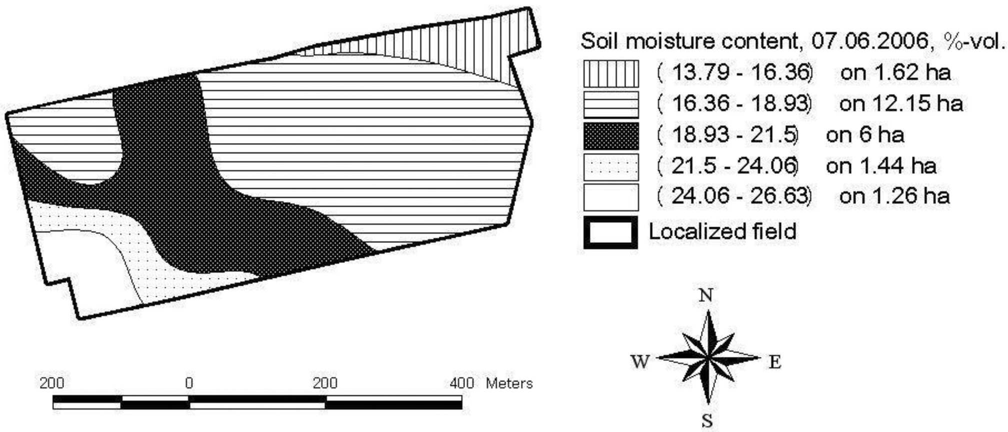

Fig. 6. Maps of soil moisture content (7. 6. 2006)

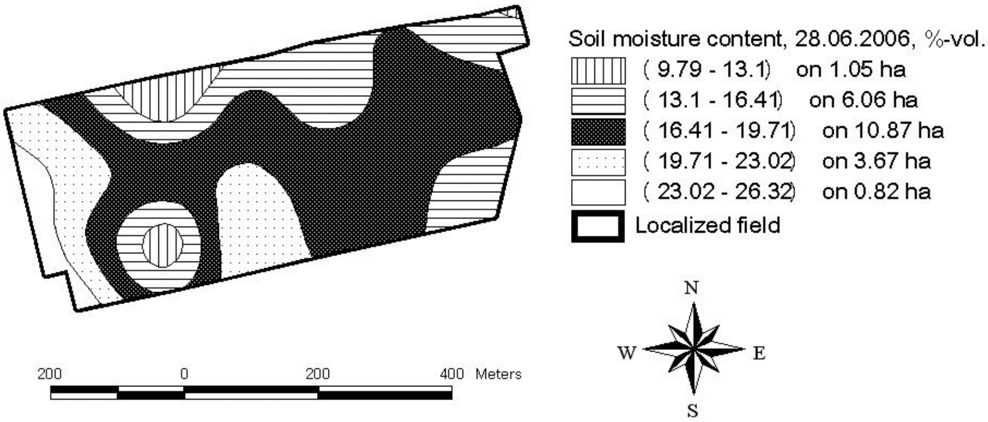

Fig. 7. Maps of soil moisture content (28. 6. 2006)

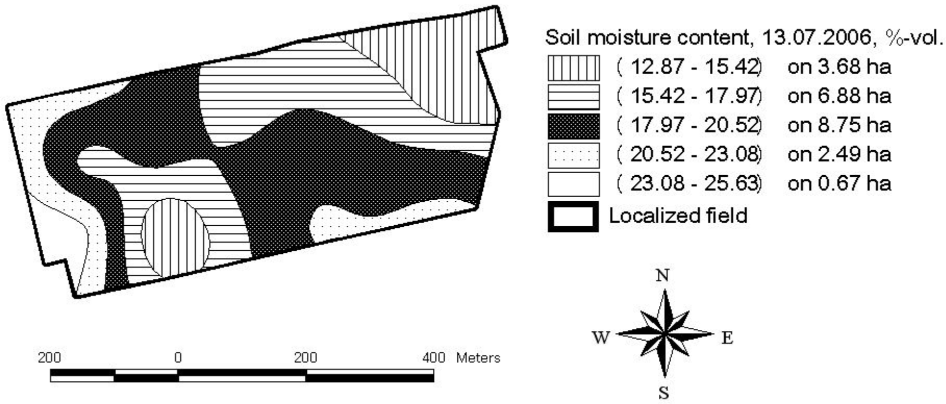

Fig. 8. Maps of soil moisture content (13. 7. 2006)

up a specific position in the crop production; this crop is grown on the area of about 200 ha.

The position of the field under investigation is shown in Fig. 3, with the surface area of 22 ha and with 19 monitoring points (output from the ArcView 3.2; Esri, NY, USA). The crop grown: potatoes – Victoria variety; soil: alkaline (pH 7.4).

Soil moisture and soil hydrological coefficients

The resulting map of the field capacity (FC) is shown in Fig. 4. The field capacity ranged between 28.80% and 30.88% by vol. The dominant interval was that from 29.22% to 29.63% on the area of 8.75 ha. As regards the wilting point (WP), its variation on the surface is displayed in Fig. 5 and ranged between 8.49% and 11.44% by vol. The interval from 8.49% to 9.08% occupied the area of 7.86 ha. All of the soil hydrological coefficients determined in percents by volume corresponded to the water content in millimetres in the soil layer of 10 cm.

Fig. 6 shows the spatial variability map of the soil moisture dated June 7, 2006. The soil moisture ranged between 13.79% and 26.63% by vol. The measured values of the soil moisture were in the range of limit values determined by the soil hydrological coefficients. The least represented were the intervals of the soil moisture ranging from 21.50%

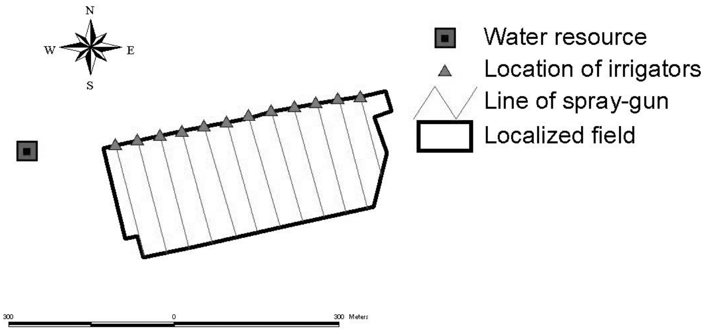

Fig. 9. Water resource and location of irrigators

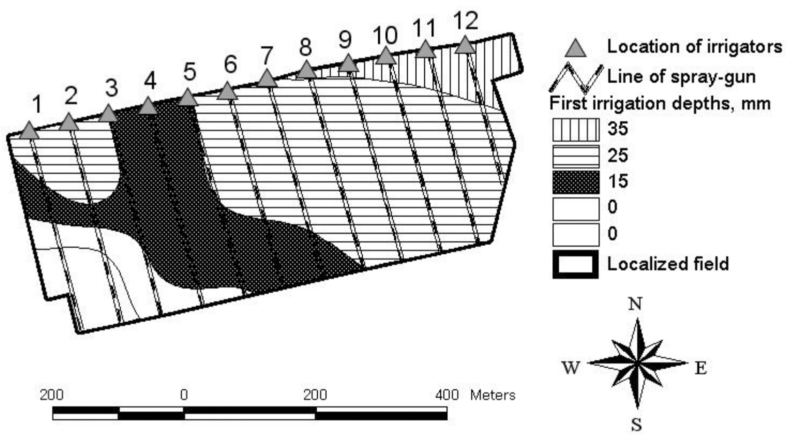

Fig. 10. First irrigation rate

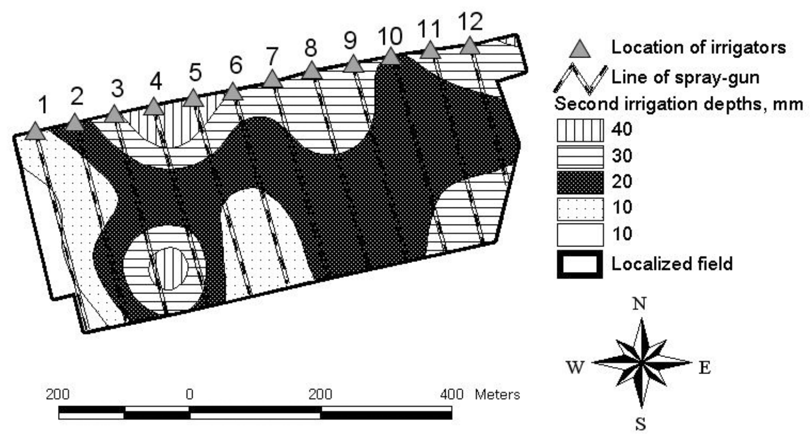

Fig. 11. Second irrigation rate

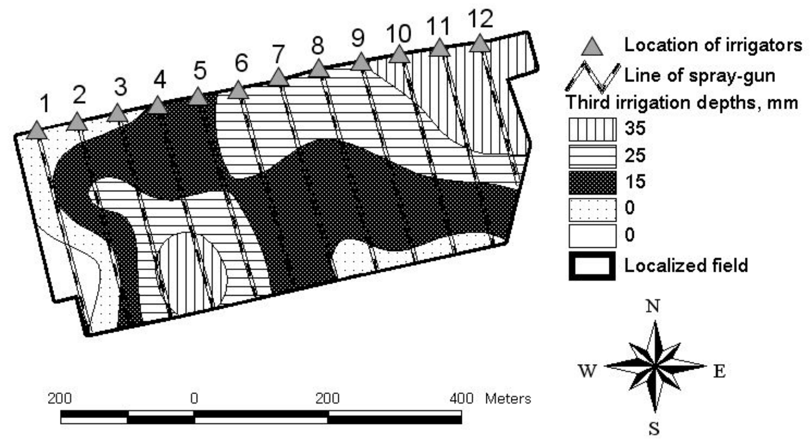

Fig. 12. Third irrigation rate

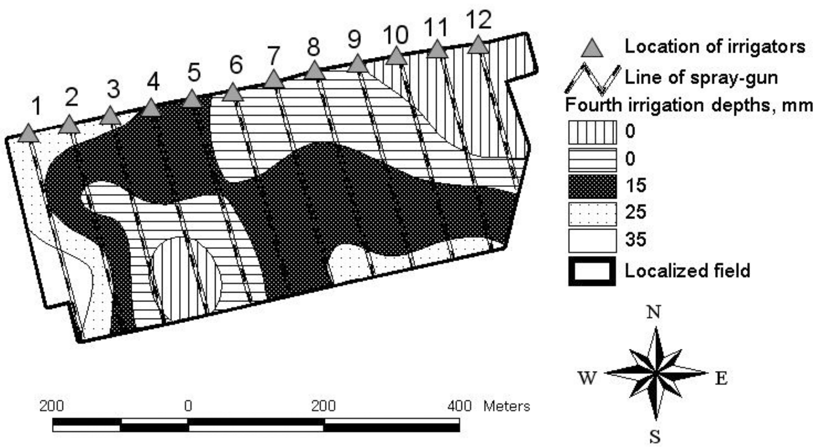

Fig. 13. Fourth irrigation rate

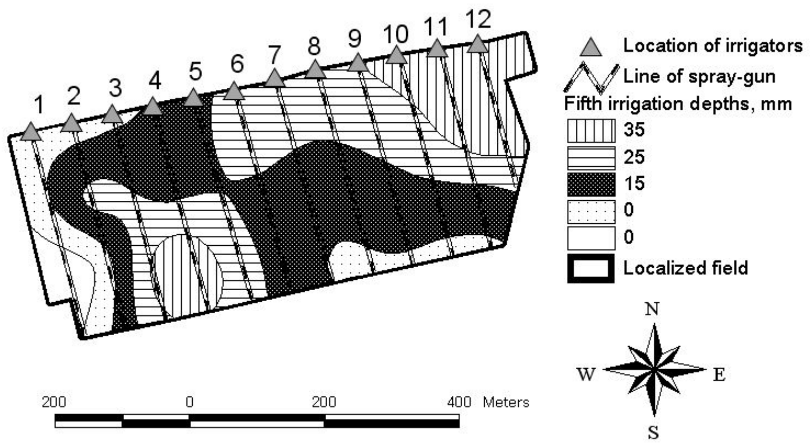

Fig. 14. Fifth irrigation rate

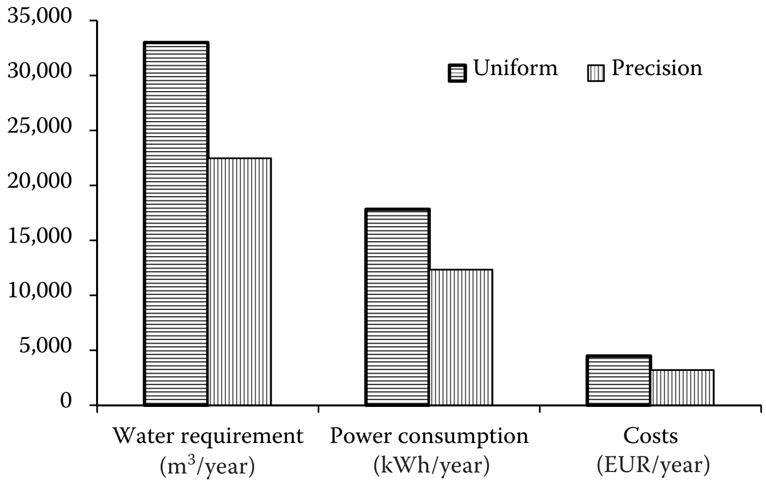

Fig. 15. Overall evaluation of the result

to 24.05% on the area of 1.4 ha (5.7% of the field) and from 24.06% to 26.63% on the area of 1.3 ha (5.5% of the field). The most represented was the interval from 16.36% to 18.93% on the area of 12.2 ha (55% of the field). Based on the resulting map of the soil moisture, it is possible to state that approximately 19.4 ha (88.18% of the field) require to be irrigated.

The subsequent date of soil moisture measuring was fixed on June 28, 2006. The resulting map is shown in Fig. 7. The soil moisture ranged from 9.79% to 26.32%. The most represented was the interval from 16.41% to 19.71% on the area of 10.8 ha (46.6% of the field). The least represented was the interval from 23.02% to 26.32% on the area of 0.8 ha (3.4% of the field). It is evident from the resulting soil moisture map that 100% of the field requires to be irrigated (22 ha) in the range from 10 to 40 mm at the graduated irrigation rates.

The spatial variability map of the soil moisture (dated July 13, 2006) was determined at repeated irrigation rate. The individual values of the soil moisture, as resulting from Fig. 8, ranged between 12.87% and 25.63% by vol. The measured values were in the range of limit soil hydrological coefficients. The most represented was the soil moisture interval from 17.97% to 20.52% on the area of 8.7 ha (39.3% of the field). The least represented was the interval between 23.08% and 25.63% on the area of 0.7 ha; this represents 3.18% of the field. The resulting map of the soil moisture revealed the need for irrigation water on 19.2 ha (87.27% of the field).

Preparing application maps and possibility to implement irrigation

The pumping station consisted of an electric motor with the output of 55 kW and pump flow of 144 m^3/h. According to the technical parameters of the irrigation machines monitored, the water flow of 26.6 m^3/h was determined for the use of nozzle diameter of 20.0 mm and nozzle pressure of 0.3 MPa. To achieve the required flow, only five irrigation machines could be connected to one pumping station. The spacing between the positions of the irrigation machines was 60 m (Fig. 9). One irrigation machine wetted a strip of the field covering a total area of 60 × 318 m. All of the 12 positions of irrigation machines were utilised.

Table 1. First position of irrigation machine

Irrigation machine	Zone 1			Zone 2			Zone 3			Zone 4		
	A	B	C	A	B	C	A	B	C	A	B	C
9	285	1,068	25	27	148	35	–	–	–	–	–	–
10	266	998	25	42	230	35	–	–	–	–	–	–
11	235	881	25	69	377	35	–	–	–	–	–	–
12	128	480	25	98	535	35	–	–	–	–	–	–

A – stage length (m); B – time of irrigation (min); C – irrigation rate (mm)

Table 2. Second position of irrigation machine

Irrigation machine	Zone 1			Zone 2			Zone 3			Zone 4		
	A	B	C	A	B	C	A	B	C	A	B	C
5	141	326	15	172	645	25	–	–	–	–	–	–
6	104	240	15	207	776	25	–	–	–	–	–	–
7	67	155	15	241	904	25	–	–	–	–	–	–
8	291	1,092	25	21	115	35	–	–	–	–	–	–

For abbreviations see Table 1

Table 3. Third position of irrigation machine

Irrigation machine	Zone 1			Zone 2			Zone 3			Zone 4		
	A	B	C	A	B	C	A	B	C	A	B	C
1	170	0	0	64	148	15	85	319	25	–	–	–
2	150	0	0	38	88	15	131	492	25	–	–	–
3	83	0	0	141	326	15	89	334	25	–	–	–
4	19	0	0	295	681	15	–	–	–	–	–	–

For abbreviations see Table 1

When determining the irrigation rate, the soil moisture map and the soil hydrological coefficients determined for the relevant part of the field were taken into account. Irrigation started on the spots where it was needed at the most – i.e. the spots with the lowest soil moisture contents.

The first irrigation rate ranged between 0 and 35 mm (zone rates of 35, 25, 15 mm; Fig. 10, Table 1–3). It was applied on the area of 19.4 ha (88.18% of the field). The irrigation rate of 35 mm was applied to the area of 1.6 ha. The area of 12.1 ha received the irrigation rate of 25 mm. The remaining part of the field obtained the irrigation rate of 15 mm (2.7 ha) and 0 mm.

The second irrigation rate ranged between 10 and 40 mm (zone rates of 40, 30, 20, 10 mm; Fig. 11). It was applied to the whole of the field (22 ha). The most represented was the irrigation rate of 20 mm on the area of 10.8 ha. The least represented was the irrigation rate of 40 mm (on the area of 1.1 ha). The irrigation rate of 30 mm was applied to the area of 6.1 ha.

Table 4. Cost of uniform and precision irrigation rate

Indication	Item	Value	
		uniform irrigation rate	variable irrigation rate
Annual cost			
$_{r}N_{mC}$	annual cost of irrigation (EUR/year)	2,011.35	1,709.83
$_{r}N_{eV}$	annual cost of water (EUR/year)	2,469.56	1,491.85
Sum (EUR/year)		4,480.92	3,201.68
Saving of cost (EUR/year)		1,279.23	
Unit cost			
$_{j}N_{mC}$	unit cost of irrigation (EUR/year)	18.28	15.54
$_{j}N_{eV}$	unit cost of water (EUR/year)	19.92	13.56
Sum (EUR/year)		38.2	29.1
Saving of cost (EUR/year)		9.1	

The area of 19.2 ha (87.27% of the field) received **the third irrigation rate** within the range from 0 to 35 mm (35, 25, 15 mm; Fig. 12). The figure shows that the irrigation rate of 35 mm (on the area of 3.6 ha), the irrigation rate of 25 mm (on the area of 6.8 ha), and the irrigation rate of 15 mm (the remaining area) were applied. Part of the area remained with no application of irrigation water (3.2 ha).

The fourth irrigation rate ranged between 0 and 35 mm (Fig. 13). The irrigation rate of 25 mm was applied to the area of 2.4 ha. The irrigation rate of 15 mm remained unchanged.

The last irrigation rate was applied to the area of 19.2 ha (87.27% of the field), that is, in the range from 0 to 35 mm (Fig. 14). The irrigation rate of 35 mm was applied to the area of 3.7 ha. The irrigation rate of 25 mm was applied to the area of 6.8 ha.

Crop yields and cost assessment

The yield of potatoes was determined according to the specified methodology. Only one variety (Victoria) with the average yield of 41.89 t/ha was grown in the field under investigation (22 ha).

In terms of irrigation accuracy, there are two basic methods for the application of the irrigation rate:

- conventional irrigation with a uniform rate applied to the whole field;
- precision irrigation with a variable rate applied to the whole field.

The method of applying irrigation significantly influences the size of the cost incurred.

When precision irrigation was implemented, it was possible to use only the machines available to the holding, namely: tractor Z 7211 (Zetor, Martin, Slovak Republic) and reel hose irrigation machines Bauer 90/300 (BAUER Gesellschaft, Voitsberg, Austria) with an on-board computer equipped with the basic software.

Cost calculation under precision irrigation and under uniform water application was done according to the introduced methodology. Moreover, variable rate irrigation requires to take account of the following input costs (they were neither taken into account in the work nor calculated):

- price of the program for the preparation of maps, for example ArcView 3.2;
- price of the GPS navigator, for example eMAP;
- costs for laboratory analyses, the determination of soil hydrological coefficients (FC, WP) in a laboratory;
- costs for the determination of the soil moisture, for example soil sample rings (for undisturbed soil sampling), HH2 Moisture Meter and WET Sensor;
- labour costs for the maps preparation.

A constant irrigation rate of 30 mm was considered under conventional irrigation.

The measurements were undertaken in the investigated field in the year 2006. The average diesel fuel price during this year was 0.83 EUR/l. The insurance for the tractor Z 7211 amounted to 42.62 EUR/year. The hourly rate for the tractor operator was 2.65 EUR/h, and the hourly rate for the irrigation operator was 2.65 EUR/h. The irrigation rate was changed by the irrigation operator, and his wage for this work amounted to 2.65 EUR/h. The cost for garaging the machine represented 2.16 EUR/m^2.

There were consumed 1,021.44 m^3/ha of water in the field of 22 ha in the experiment with precision irrigation. The electric power consumption to drive the pump was 560.9 kWh/ha. At a uniform irrigation rate, the consumption would be 1,500 m^3/ha of water. When applying such amounts of water (33,000 m^3), the planned electric power consumption was 17,832.65 kWh (810.58 kWh/ha). Water saving represented 478.56 m^3/ha (1,500 to 1,021.44; 31.9%). The electric power saving was 249.68 kWh/ha. The total cost for irrigation implementation was in the value of 1,709.83 EUR/year (with no energy subsidies, with no water cost). The unit cost amounted to 15.54 EUR/ha. The cost of consumed water was 1,491.85 EUR/year (without any consumed water subsidies). The unit cost of water reached 13.56 EUR/ha. Therefore, the total unit cost amounted to 29.1 EUR/ha. In the investigated agricultural holding, the total unit cost under uniform irrigation rate was 38.2 EUR/ha, thus showing the saving of 9.1 EUR/ha (23.8%; Fig. 15, Table 4). In favour of precision irrigation.

The obtained knowledge was confirmed by the research into precision irrigation conducted in the world. Hedley et al. (2009) identified preciously the performance indicators of variable rate irrigation; in their work, they described in detail the methods for soil conditions mapping with respect to soil hydraulic properties. That enabled to determine accurately the amount of the consumed water, water losses, nitrogen depletion from the soil depending upon concrete conditions of the selected fields. Water saving was from 9% up to 19% with an adequate reduction of energy consumption. It follows that water saving in our experiments was higher.

Perry and Pocknee (2003) also achieved water saving when an agricultural crop was irrigated precisely. They transformed the application map into the Canlink 3000 control unit.

Hedley et al. (2009) evaluated the benefits of using variable rate irrigation for selected crops (dairy pasture, potatoes, maize grain). They reached water saving of 9% (dairy pasture), 13% (potatoes) and 19% (maize grain). That enabled to save the operating costs in the value of NZD 35 1/ha (potatoes), NZD 88 1/ha (pasture) and NZD 149 1/ha (maize). The maximum water saving was revealed in the location of maize.

CONCLUSION

The practical implementation of the presented methodology supported the possibility to apply precision irrigation. Experimental measurements confirmed the economic effectiveness of the suggested method. Under variable rate irrigation, the total cost was reduced by 9.1 EUR/ha and this represented the saving of 23.8% to the benefit of precision irrigation. The water saving amounted to 478.56 m^3/ha, the same expressing the value of 31.9%. The implementation of information technology in the given case enabled to process graphically the variability of input and output conditions needed for the implementation of precision irrigation in practice.

References

Derbala A., Sourell H., 2002. Development and evaluation of mobile drip irrigation with center pivot machine. In: Proceedings 8th International Congress on Mechanization and Energy in Agriculture, October 15–17, 2002. Kusadas, Turkey.

Fraisse C.W., Heermann D.F., Duke H.R., 1995. Simulation of variable water application with linear-move Irrigation systems. Transactions of the ASABE, *38*: 1371–1376.

Hedley C., Yule I., Tuohy M., Vogeler I., 2009. Key Performance Indicators for Variable Rate Irrigation Inplementation on Variable Soils. St. Joseph, ASABE.

King B.A., Stark J.C., Wall R.W., 2006. Comparison of site-specific and conventional uniform irrigation management for potatoes. Applied Engineering in Agriculture, *22*: 677–688.

Nozdrovický L., Rataj V., Galambošová J., Kollárová K., Macák M., Halva J., Tuček J., Koreň M., Smreček R., 2008. Presné pôdohospodárstvo. IMPL Ementácia s podporou informačných technológií a techniky (Precision Farming. Implementation with the Support of Information Technologies and Techniques). Nitra, SPU in Nitra: 168.

Perry C., Pocknee S., 2003. Precision pivot irrigation controls to optimize water application. In: Proceedings of the 2003 Irrigation Association Meeting, San Diego: 86–92.

Rataj V., 2005. Projektovanie výrobných systémov – Výpočty a analýzy (Projection of the Production Systems – Calculations and Analyses). Nitra, SPU in Nitra: 120.

Sadler E.J., Camp C.R., Evans D.E., Millen J.A., 2002. Spatial variation of corn response to irrigation. Transactions of the ASABE, *45*: 1869–1881.

Sourell H., 2003. Progressive irrigation technique for one certain und ecologically plant production. Landbauforschung Völkenrode Sonderheft, *258*: 107–108.

Sourell H., Al-Karadsheh E., 2003. Precision irrigation toward improving irrigation water management. ICID-CIID. Available at http://afeid.montpellier.cemagref.fr/mpl2003/AtelierTechno/AtelierTechno/Papier%20Entier/Sourell.pdf

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