INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

No III/1/2018, POLISH ACADEMY OF SCIENCES, Cracow Branch, pp. 649-658
Commission of Technical Rural Infrastructure

DOI: https://doi.org/10.14597/INFRAECO.2018.3.1.044

EVALUATION OF IRRIGATION EFFICIENCY IN SELECTED FIELD CROPS GROWN IN EASTERN WIELKOPOLSKA, POLAND

Piotr Stachowski, Daniel Liberacki, Paweł Kozaczyk
Poznan University of Life Sciences

Abstract

The paper presents results of a controlled field experiment with sprinkler irrigation of winter oilseed rape (Latin name) cv. Arsenal F1 Linagrain and winter wheat (Latin name) cv. Franz, conducted in the vegetation season of 2016 (dry in terms of the recorded precipitation total) on a family farm in Kobylata, the Kłodawa commune, the Wielkopolskie Province. Water requirement observed as early as April was balanced by sprinkler irrigation in seasonal application rates ranging from 75 mm (rape) to 105 mm (wheat). Sprinkling of winter rape was the factor having a highly significant effect on seed yield volume, on average from 4 plots amounting to 4.1 $t \cdot ha^{-1}$ and by 17.4% greater than the yield harvested in the non-irrigated plots (control) – of 0.6 $t \cdot ha^{-1}$. Winter wheat, at the application of sprinkler irrigation, also produced greater yields (by 24%) in comparison to the non-irrigated plots. Mean grain yield of wheat in the irrigated plots was by 1.9 $t \cdot ha^{-1}$ greater. Advisability of irrigation, apart from higher yielding, may also be indicated by water use efficiency in these crops. Every mm of sprinkled water caused an increase in of rape by 7.9 kg, while in wheat by 17.8 kg.

Key words: sprinkler irrigation, winter oilseed rape, winter wheat, increase in seed yield, irrigation efficiency

INTRODUCTION

Plant cultivation in Poland is burdened by climate risk, resulting from harmful and adverse weather changes. These include e.g. drought periods, occurring particularly in the main regions with intensive agricultural production, covering extensive areas of the lowland, central part of Poland and are considered to be areas with exceptional water deficits (Rzekanowski *et al.* 2011) and classified by Romer (1947) as the Region of the Great Valleys. These regions are characterized by the lowest precipitation during the vegetation season, exceptionally adverse climatic water relations and increased frequency of extensive rain-free periods. This also refers to Eastern Wielkopolska, where mean annual precipitation total is 500 mm. In the vegetation periods precipitation totals range from 240 mm to 290 mm, while in dry years it is maximum half of that value. This region is characterized by one of the greatest water deficits, with precipitation-free periods occurring with high frequency (Rolbiecki *et al.* 2000, Żarski *et al.* 2004, Stachowski 2009). Atmospheric droughts leading to soil droughts are frequent phenomena, occurring at irregular intervals (Żarski *et al.* 2013).

Drought during the period of increased water requirement of plants results in yielding decline, both quantitative and qualitative. This is connected with the adverse effect of water deficits on plant growth and development patterns (Żarski 2009). In contrast to countries located in warmer climatic zones, in Poland crop irrigation is generally applied as an intervention measure, i.e. deficit irrigation. The objective is to supplement periodical deficits of precipitation in relation to water requirements of crops (Rzekanowski *et al.* 2011). Winter oilseed rape is the most important oil crop produced in Poland. The economic role of oilseed rape results from the fact that it is practically the only crop providing oil of satisfactory quality, and it is the basic raw material for the food and chemical industries. Moreover, this plant is also an excellent forecrop for cereals and thanks to its high protein content it is an important raw material for the feed industry. The increased importance of this crop has been a consequence of intensive breeding for quality within the last 40 years. Both in Poland and worldwide these breeding efforts have produced cultivars yielding seeds, which are a source of both quality oil and protein feed (Budzyński *et al.* 1996). Precipitation levels required by rape as specified by Dzieżyc (1988) are high and amount to 600-700 mm annually, while in soils of considerable retention capacity they may be by approx. 100 mm lower. Nevertheless, they are not met over most of Poland. Starting from the flower bud stage until seed setting oilseed rape is particularly sensitive to water deficits (Budzyński *et al.* 1996). That period of its growth is critical. Water shortages are manifested in reduced tillering, causing bud desiccation and shedding, flower shedding, while the number of siliques and seeds is reduced (Berbeć and

Kołodziej 2006; Dzieżyc 1988), which may result in a decreased fat content (Budzyński *et al.* 1996).

Precipitation shortages may be supplemented with irrigation (Dudek *et al.* 2011), with sprinkler irrigation applied most frequently in the case of field crops. Sprinkling of winter rape in Poland has been investigated in a limited number of studies. This may have been caused by the unsatisfactory results of this measure despite the additional water consumption. The obtained increase in seed yield ranged from 0.1 to 0.3 $t \cdot ha^{-1}$ on light soils, while on heavy alluvial soil in the Żuławy region either no increase or even a decrease in yield was observed (Grabarczyk *et al.* 1989). To a considerable extent the effects of sprinkling in rape depend on soil type, mineral, particularly with nitrogen, as well as precipitation levels.

In the case of soil and climatic conditions found in the Wielkopolska region the advisability of sprinkler irrigation in wheat culture is disputable. While under varying precipitation conditions it may be justified by the produced yields, as indicated by some researchers (Dzieżyc 1988, Rudnicki *et al.* 1996), its economic efficiency is low (Żarski *et al.* 2004). For this reason in practice winter wheat is rarely irrigated, even though, as shown by experiments conducted to date, winter wheat responded to irrigation with an average increase in seed yields by 0.61 $t \cdot ha^{-1}$ (Chylińska, 1996). Production effects of sprinkling depended on the region, weather conditions (the volume and distribution of precipitation) and the agricultural value of the soil complex, ranging from 0.2 to 1.1 $t \cdot ha^{-1}$. In the experiments conducted by Grabarczyk *et al.* (1989) and Borówczak *et al.* (1996), the effect of sprinkler irrigation on yields in wheat was non-significant or even adverse, as yields decreased. In the opinion of many researchers, economic efficiency of sprinkling in the case of winter wheat should be observed in the climatic zones with the lowest precipitation and soils with low retention capacity (Rzekanowski *et al.* 2011).

MATERIAL AND METHODS

The controlled field trial on the application of sprinkler irrigation of winter rape cv. Arsenal F1 Linagrain and winter wheat cv. Franz were conducted in the 2016 vegetation period in a field belonging to a family farm in Kobylata, the Kłodawa commune, the Koło county, the Wielkopolskie Province. A total of 4 experimental sites of 4 ha each were established. 4 plots of 1 ha were established on each of the 4 experimental sites for the two analyzed crops. In each experimental site the following variants were applied: one plot with irrigated wheat, the next plot was the variant with no sprinkling applied, and an analogous pattern for winter rape. Water was supplied to the plots using a surface mobile sprinkler system, composed of polyethylene pipelines placed along the irrigated vegetation belts and pop-up sector sprinkler heads. Sprinkling was performed using a mobile IRTEC 90G/E4 500 reel sprinkler dedicated to field crop irrigation. Sprinkling was performed using PE hoses of 90 mm in diameter and 500 m in length. The sprinkler nozzle of 20 mm in diameter at the adopted maximum single irrigation rates of 25 mm was utilized. The following operating parameters were obtained (sprinkler pressure 3.0 bar, sprinkler radius 35.0 m, irrigated belt width 56.0 m, water use 26 $m^3 \cdot h^{-1}$.

For plots cropped to winter rape the following fertilization scheme was adopted assuming yield at 4.0 $t \cdot ha^{-1}$ N at a rate of 215.00 $kg \cdot ha^{-1}$, (pre-sowing application of Pulrea 46% N at 100 $kg \cdot ha^{-1}$), in the early spring followed by Saletrosan NS 26-13 at 350 $kg \cdot ha^{-1}$ and the second application of Zaksan 32% N at 200 $kg \cdot ha^{-1}$, P_2O_5 at 100.00 $kg \cdot ha^{-1}$ (as 500 $kg \cdot ha^{-1}$ Polifoska 6 NPKS 6-20-30-7), K_2O at 220.00 $kg \cdot ha^{-1}$ as Polifoska 6 NPKS 6-20-30-7 and 100 $kg \cdot ha^{-1}$ 60% K_2O potash salt in the early spring, S at 45.00 $kg \cdot ha^{-1}$ as Polifoska 6 NPKS 6-20-30-7, Mg as Mg O at 35.00 $kg \cdot ha^{-1}$, Ca as CaO at 225.00 $kg \cdot ha^{-1}$, as pelleted GRADE I Extra 50CaO at 500 $kg \cdot ha^{-1}$. For plots cropped to winter wheat the following scheme was adopted (at the assumed yield of 7.0 $kg \cdot ha^{-1}$: N at 190.00 $kg \cdot ha^{-1}$), pre-sowing application of Pulrea 46%N at 100 $kg \cdot ha^{-1}$, followed in the early spring by the application of Saletrosan NS 26–13 at 250 $kg \cdot ha^{-1}$ and the second application of Zaksan 32% N at 200$kg \cdot ha^{-1}$, P_2O_5 at 80.00 $kg \cdot ha^{-1}$ as 350.00 $kg \cdot ha^{-1}$ Polifoska 6 NPKS 6-20-30-7, applied before sowing mixed into the soil, K_2O at 100.00 $kg \cdot ha^{-1}$ as Polifoska 6 NPKS 6-20-30-7, S at 25.00 $kg \cdot ha^{-1}$, as Polifoska 6 NPKS 6-20-30-7 applied before sowing.

Irrigation dates were selected using the method proposed by Grabarczyk *et al.* (1989), based on precipitation levels recorded at the automatic weather station of the KWB Konin lignite mine in Kleczewo. In the vegetation period of 2016 mean air temperature was 17.5°C and it was by 1.4°C higher than the multiannual mean. In turn, the precipitation total of 245 mm was lower (by 94 mm) than the mean precipitation total in the vegetation seasons of the multiannual period 1990–2015.

The experiment was conducted on light soils: and rusty podsolic soil, formed from fluvioglacial sands lying over shallowly deposited sandy loam and loamy sands, classified as the good wheat and very good rye soil complex. The content of the silt and clay fraction in the 0 – 50 cm layer was 18%, while in the 51 – 100 cm layer it amounted to 34%. Water reserves in the 1-m soil layer at field capacity ranged from 180 to 205 mm. In experimental site no.1 the topsoil was composed of heavy loamy sands (of 15 cm in thickness), while below they were medium loamy sands (at a layer of 40 cm), overlying light loose sand (a layer of 70 cm in thickness). In experimental site no. 2 the top layer was composed of heavy loamy sands (a layer 25 cm thick) overlying loamy sand (45cm). In experimental site no. 3 the top layer was formed by medium loamy sands (15 cm), overlying a 30-cm layer of loamy sands. In turn, in experimental site no.

4 the top layer consisted of medium sands deposited in a 20-cm layer overlying medium loamy sand (a layer of 40 cm in thickness).

The seasonal irrigation rate was 105 mm for wheat and 75 mm for rape. The adopted sprinkling rates were verified based on the monitoring of available water in periods of increased requirement from the 3rd decade of April to the 1st decade of June applying the water balance method proposed by Drupka (1976).

RESULTS

High rainfall requirement of winter rape is rarely met under the climatic conditions of Poland, mainly due to the insufficient precipitation or its uneven distribution (Żarski and Dudek 2009). The greatest water requirement of plants is observed in the period from the onset of spring vegetation to generative maturity when plant structure and tillering are determined, buds and flowers are formed and seeds are set (Budzyński *et al.* 1996).

Water requirement of oilseed rape increases particularly in the period of spring vegetation when water supply deficit results in adverse effects, e.g. limited tillering, desiccation and drop of buds as well as flower shedding, and thus decreasing the number of siliques and seeds (Dudek *et al.* 2013). In the experiment with sprinkler irrigation of winter rape the total irrigation rate was 75 mm. The greatest requirement for deficit sprinkling was observed in 2016, when it was found as early as April and May (Fig. 1). In May there was a long (18-day) spell of rain-free days as well as a longer (25-day) spell at the turn of April and May and the first decade of June, when no significant rainfall was recorded. The irrigation season started already on April 20 and it lasted until June 15. During that period a total volume of 75 mm water was sprinkled in 6 application doses (Tab.1).

Sprinkling of winter rape was a highly significant factor influencing seed yield, as its mean yield from the 4 experimental sites was 4.1 $t\cdot.ha^{-1}$ and it was by 0.6 $t\cdot.ha^{-1}$ higher (17.4%) than rape yields obtained in non-irrigated (control) sites (tab. 2). Such an increase in seed yields of rape needs to be considered high and comparable to that reported by Dudek *et al.* (2013) in the period from 2009 to 2010 on light soils in the years with similar weather conditions. The advisability of irrigation, apart from the observed increase in yields, may be confirmed by the efficiency of water use by rape. Each millimeter of sprinkled water resulted in an increased production from 5.5 (site no. 4) to 9.9 kg (site no. 1), on average 7.9 kg, at the applied irrigation rate of 25 mm. The comparison of the sprinkler irrigation effects found in this study with literature data is rather difficult due to the limited number of such trials, particularly since they were conducted on other cultivars, differing greatly from the currently cultivated ones. Berbeć and Kołodziej (2006), citing studies conducted in Poland and abroad, stated that the effects of sprinkler irrigation, apart from soil conditions, are also dependent on nitrogen fertilization levels. Irrigation of oilseed rape on sandy soil resulted in a yield increase by 11%, while on loamy soil it was by 18%. Fertilization with nitrogen applied together with irrigation increased seed yield from 5% to 35%.

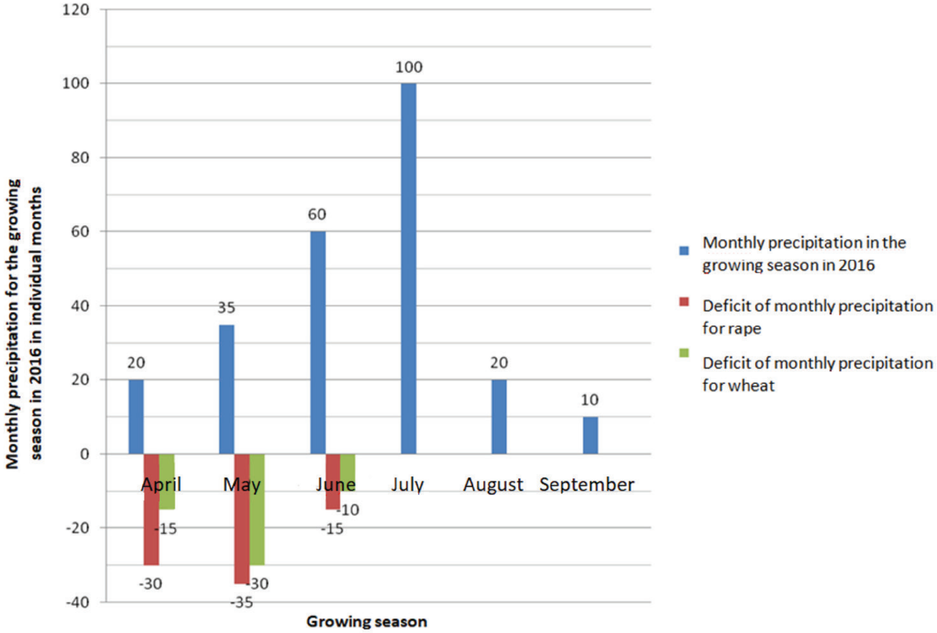

Figure 1. Monthly precipitation totals in the vegetation period of 2016 and precipitation deficit in analyzed crops Source: The authors' study

Seed yields of winter wheat on non-irrigated sites amounted to 7.8 $t.ha^{-1}$ and depended solely on the volume and even more importantly – on the distribution of precipitation. At the application of sprinkler irrigation wheat produced higher yields, in the tested sites by on average 24%. Sprinkling increased seed yields by on average 1.9 $t.ha^{-1}$. Water use efficiency for a 1 mm water sprinkler irrigation rate averaged 17.8 kg. The results indicate a high potential of winter wheat for cultivation using sprinkler irrigation on soils with low retention capacity, where water supply of plants is determined almost exclusively by precipitation occurring during the spring vegetation period.

A detailed analysis of the results concerning the effect of sprinkling on an increase in yields in the two crops (winter rape and winter wheat) confirmed that in a dry vegetation period (2016) in terms of the precipitation total the effect of irrigation on an increase in their yielding was considerable. The recorded increase was greater in the case of wheat yield by 24%, while the increase in the yield of winter rape was on average by 17%.

Table 1. Water requirement and water deficit of analyzed crops

Vegetation period 2016	Water requirement Mm		Water deficit mm		Irrigation rates mm	
	Winter wheat	Winter rape	Winter wheat	Winter rape	Winter wheat	Winter rape
April	35	50	-15	-30	25	30
May	65	70	-30	-35	25	35
June	70	75	-10	-15	25	40
July	60	30	40	70	0	0
August	0	0	20	20	0	0
September	0	0	10	10	0	0

Source: the authors' study

Table 2. Productivity of irrigation in winter rape in 2016 ($t{\cdot}ha^{-1}$)

Experimental site	No. 1	No. 2	No. 3	No. 4	Average
Wo – yield of non-irrigated crops	3.3	3.5	3.5	3.7	3.5
W1 – yield of irrigated crops	4.1	4.1	4.1	4.1	4.1
Increase in yield W1-Wo	0.8	0.6	0.6	0.4	0.6
%	24.2	17.1	17.1	11.0	17.4
$Kg{\cdot}mm^{-1}$	9.9	8.1	8.1	5.5	7.9

Source: The authors' study

Table 3. Effect of sprinkler irrigation on winter wheat grain yields ($t{\cdot}ha^{-1}$)

Experimental site	No. 1	No. 2	No. 3	No. 4	Average
Wo – yield of non-irrigated crops	7.6	7.8	7.9	8.0	7.8
W1 – yield of irrigated crops	9.7	9.7	9.7	9.7	9.7
Increase in yield W1 – Wo	2.1	1.9	1.8	1.7	1.9
%	27.6	24.4	22.8	21.3	24.0
$Kg{\cdot}mm^{-1}$	19.3	18.1	17.2	16.4	17.8

Source: The authors' study

The analyses confirmed a direct effect of sprinkler irrigation on productivity of the investigated winter crops: wheat and oilseed rape. It was manifested not only in the increase of yields, but it also had an advantageous effect on the activity of physiological processes in plants, as well as their morphological and anatomical structure, as shown by the monitoring surveys conducted on site. The results confirmed observations reported by other authors that the volume of yield increased under the influence of irrigation measured by the increase in yield per 1 mm irrigation water was significantly greater. Both farming theoreticians and practitioners indicate that the greatest effects of irrigation are obtained on light soils with the sandy texture. They are characterized by low water capacity and thus continuous natural water supply of plants may never be provided. Results of this study also confirmed that irrigation of rape and wheat on light soils is a measure providing high productivity, as it was indicated by other researchers (Rzekanowski *et al.* 2011). Summing up, it may be stated that water requirements of selected field crops and irrigation efficiency under the conditions found in Poland varies. There is a need to consider irrigation of crops as an important measure leading to an increase in yielding, which may ensure a certain degree of independence from adverse weather conditions, particularly in regions of prevalent water deficit, such as Eastern Wielkopolska.

CONCLUSIONS

1. Analyses and field experiment confirmed that the greatest and most frequent repeated requirement for sprinkler irrigation in the case of rape and winter wheat, supplementing precipitation deficits were observed in Eastern Wielkopolska at the turn of April and May and at the turn of May and June.
2. Seed yield of winter rape grown on light soils with no irrigation applied amounted to 3.5 $t \cdot ha^{-1}$, while at the application of sprinkler irrigation it increased by 17.4% to 4.1 $t \cdot ha^{-1}$.
3. Yield of winter wheat from non-irrigated sites in the dry vegetation period of 2016 ranged from 7.60 $t \cdot ha^{-1}$ to 8.0 $t \cdot ha^{-1}$, with mean 7.8 $t \cdot ha^{-1}$. In turn, in sites irrigated using a reel sprinkler system mean yields reached 9.7 $t \cdot ha^{-1}$.
4. Production efficiency of the applied sprinkler irrigation were confirmed by the effect of 1 mm sprinkled water on an increase in crop yields, to 7.9 kg in the case of winter rape and 17.8 kg in winter wheat. The lower the adopted application rate, the greater the efficiency of sprinkler irrigation.

REFERENCES

Berbeć, S., Kołodziej, B. (2006). *Rośliny przemysłowe, specjalne i zielarskie.* PWRiL Poznań, 421-444

Borówczak, R., Maciejewski, T., Grześ, S., Szukała, J. (1996), *Efekty deszczowania i nawożenia niektórych roślin uprawnych w warunkach Wielkopolski w latach 1989-1992* Zesz. Probl. Post. Nauk. Rol., 438: 103-110

Budzyński, W., Ojczyk, T. (1996). *Rzepak – produkcja surowca olejarskiego.* Wyd. ART Olsztyn.

Chylińska, E. 1996. *Nawadnianie jako czynnik kształtujący wysokość i jakość plonu rzepaku ozimego* Zesz. Probl. Post. Nauk Roln., 438: 147–154

Dudek, S., Kuśmierek-Tomaszewska, R., Żarski, J. (2011). *Wpływ deszczowania i nawożenia azotowego na plonowanie rzepaku ozimego.* Infrastructure and ecology of rural areas*,* 5: 193–202

Dudek, S., Kuśmierek-Tomaszewska, R., Żarski, J., Szterk, P. (2013). *Ocena potrzeb i efektów deszczowania rzepaku ozimego w rejonie Bydgoszczy.* Infrastructure and ecology of rural areas, Nr 1/II/2013: 51 – 62

Dzieżyc, J. (1988). *Rolnictwo w warunkach nawadniania.* PWN Warszawa.

Drupka, S. (1976). *Techniczna i rolnicza eksploatacja deszczowni* PWR i L, Warszawa, 310

Grabarczyk, S. (1987). *Efekty, potrzeby i możliwości nawodnień deszczownianych w różnych regionach kraju.* Zesz. Prob. Post. Nauk Rol., 314: 49–64

Grabarczyk, S., Rytelewski, L., Kasińska, D. (1989). *Polowe zużycie wody przez rośliny uprawne w warunkach Kujaw.* Zesz. Probl. Post. Nauk Roln., 343: 151–155.

Romer E. (1916): Geograficzno – statystyczny atlas Polski. Wydawnictwo Warszawa i Kraków, Gebethner i Woff 1916.

Rolbiecki, S., Żarski, J., Grabarczyk, S. (2000). *Yield-irrigation relationships for field vegetable crops grown in central Poland.* Acta Horticulturae, 537: 867–870.

Rudnicki, R., Wasilewski, P., Urbanowski, S. (1996). *Reakcje pszenicy ozimej i żyta na ilość i rozkład opadów a celowość ich nawadniania na glebie lekkiej.* Zesz. Probl. Post. Nauk. Rol., 438: 33–41.

Rzekanowski, Cz., Żarski, J., Rolbiecki, S. (2011). *Potrzeby, efekty i perspektywy nawadniania roślin na obszarach szczególnie deficytowych w wodę.* PAN Postępy Nauk Rolniczych, 1: 51–63

Stachowski, P. (2009). *Celowość stosowania nawodnień deszczownianych w zagospodarowaniu rolniczym gruntów pogórniczych.* Annual Set The Envinonment Protection, 11: 1131–1142

Żarski, J., Dudek, S. (2001). *Wpływ deszczowania i nawożenia azotowego na plonowanie pszenicy ozimej.* Zesz. Prob. Postęp. Nauk. Roln., 478: 399–404

Żarski, J., Rolbiecki, S., Dudek, S., Rolbiecki, R., Rzekanowski, C. (2004). *Potrzeby i efekty nawadniania roślin w rejonie Bydgoszczy.* Bilanse wodne ekosystemów rolniczych AR Wrocław, 187–203

Żarski, J. (2009): *Efekty nawadniania roślin zbożowych w Polsce.* Infrastructure and ecology of rural areas, 3: 29–42

Żarski, J., Dudek, S. (2009). *Zmienność czasowa potrzeb nawadniania wybranych roślin w regionie Bydgoszczy.* Infrastruktura i Ekologia Terenów Wiejskich, 3: 141–149

Żarski, J., Dudek, S., Kuśmierek-Tomaszewska, R., Rolbiecki, R., Rolbiecki, S. (2013). *Prognozowanie efektów nawadniania roślin na podstawie wybranych wskaźników suszy meteorologicznej i rolniczej.* Annual Set The Environment Protection, 15: 2185–2203

Corresponding author: Eng. Piotr Stachowski, PhD, DSc
Eng. Daniel Liberacki, PhD, DSc
Eng. Paweł Kozaczyk, PhD
University of Life Sciences in Poznan
Institute of Land Improvement, Environmental Development and Geodesy
ul. Piątkowska 94
PL 60-649 Poznań
phone: +48 (61) 846 64 26
e-mail: pstach@up.poznan.pl

Received: 14.05.2018
Accepted: 06.08.2018