https://doi.org/10.17221/736/2018-PSE

Reduction of surface runoff on sloped agricultural land in potato cultivation in de-stoned soil

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Citation: Vejchar D., Vacek J., Hájek D., Bradna J., Kasal P., Svobodová A. (2019): Reduction of surface runoff on sloped agricultural land in potato cultivation in de-stoned soil. Plant Soil Environ., 65: 118–124.

Abstract: Regarding the increased surface runoff from production areas, wide-row crops grown on slopes are considered risk crops. By reducing the surface runoff, it is possible to mitigate the negative effects on both the soil and the plants and positively influence the subsequent production, e.g., after application of de-stoning before planting. During this research, the tied ridging method was applied during planting by a two-row planter in both central and tractor trail furrows in potato rows and on the slope of 8.8% compared to a control plot without this treatment. Rainfall and surface water runoff were monitored, and the crop yields were compared. During three monitored years, up to 86% of the runoff water in the central furrows was saved compared to the control, whereas it was up to 72% in the wider furrows for tractor travel. The total yield was increased on the treated area, however, the increase could not be statistically proven.

Keywords: soil conservation; water retention; *Solanum tuberosum* L.; furrow diking; basin tillage

An important part of the water cycle is surface runoff, which is influenced by factors such as the slope of the surface, precipitation intensity, precipitation event duration, initial moisture content of the soil, as well as proportional coverage by vegetation. The runoff delay time decreases with increasing precipitation and slope intensity, and inversely the infiltration rate decreases with these parameters (Mu et al. 2015). Given the increase in surface runoff from production areas of wide-row crops, e.g., the production of potato on sloped land (Edwards et al. 2000); these represent risky crops in the Czech Republic as well as generally in the world. Other hazards in the cultivation of these crops are susceptibility to soil crusting, soil erosion and considerable stress on the plants during drought, all of which are subject to considerable weather fluctuations (Rulfová et al. 2017). Many potato production areas in the Czech Republic are situated in the Bohemian-Moravian Highlands, characterized by hilly terrain. So far, the potato cultivation technology in this area has mostly employed soil de-stoning. This influences the physical properties of soil such as porosity values that are relatively higher, and the relative soil moisture along with the maximum water holding capacity that are significantly lower compared to conventional technology (Čepl and Kasal 2001).

A solution to excessive water runoff from sloped land are methods of soil preservation applied in the furrows between rows of crop creating reservoirs to catch surface runoff. These are called e.g. tied ridging, furrow diking or dammer diking. This treatment should be carried out as soon as possible after planting or during planting with a simple and relatively inexpensive machine that creates accumulation spaces to capture precipitated water and

Supported by the Research Institute of Agricultural Engineering, p.r.i., Project No. RO0618; by the Potato Research Institute Havlíčkův Brod, Ltd., Project No. MZE-RO1618, and by the Ministry of Agriculture of the Czech Republic, Project No. QJ1610020.

https://doi.org/10.17221/736/2018-PSE

thereby reduce surface water runoff from the land (Nuti et al. 2009).

The tied riding method and similar soil treatments have already been the subject of many research projects (Alva et al. 2002, Truman and Nuti 2010). This system for reducing water runoff from production areas was developed not only to capture and more efficiently use rain water, but it is also effective in irrigation systems for example in the Mediterranean conditions, with dry climate and low water availability in summer months (Nuti et al. 2009, Truman and Nuti 2009, Silva 2017). This method of soil preservation can also mitigate soil nutrient depletion, for example in sandy soils (Munodawafa 2007, Gordon et al. 2011), where this is tied to reduced soil particle loss from production areas. A similar conclusion was reached by Xia et al. (2014), who, after runoff preventing the treatment to the soil, found a decrease in surface runoff as well as a significant decrease in phosphorus loss and a moderate decrease in nitrogen loss.

Soil erosion is mainly dependent on surface runoff during intensive precipitation events. Interrupting or reducing the level of surface runoff can be done using protective measures, which reduces the shear stress in soil bed caused by flowing water (Kovář et al. 2012). Thus, the tied ridging method, in addition to increased water absorption, is useful as a counter-erosion measure at the same time. However, it is accompanied by some drawbacks, e.g., the retention space decreases due to sediment deposition during the growing season, where the increase in erosion rate increases strongly with increasing precipitation. On the other hand, the treated area experiences less erosion compared to the control (Sui et al. 2016). At the same time, they state, based on the research on maize, that proper formation of the reservoirs reduced both the flow rate of the surface water and the total runoff. Also, an increase in soil moisture by up to 45% and 17% in maize yields were achieved. However, in potatoes, the higher yield attributed to tied ridging compared to conventional cultivation has not yet been clearly demonstrated, even when the overall average yield from treated areas increased (Olivier et al. 2014) with the exception of Agassi and Levy (1993), where a significant effect on yield increase in potatoes was achieved in Israel.

The work aims at proving whether the tied ridging method has a positive effect on the reduction of the surface runoff in potatoes cultivated in de-stoned soils on sloped land. The second aim is to determine whether the reduced surface runoff influences the overall yield of potato tubers.

MATERIAL AND METHODS

The experiments were carried out in the years 2014–2016 at the location Valečov (49°38'16.0''N, 15°29'20.0''E) in the Vysočina region of the Czech Republic, which lies in the temperate climate zone. The test site was a part of a potato production area on an 8.8% slope. The altitude is 450 m a.s.l. The average annual temperature is 7.0°C, and the average annual precipitation is 652 mm. For the vegetation period from April till September, the average temperature is 13.2°C, and the average precipitation is 453 mm. The soil type is gleyic Cambisol (CM according to FAO soil classification system) with sandy loam structure.

Four variants of the experiment were established each year with a two-row machine: F – centre furrow; TF – tractor trail furrow; RF – centre furrow with tied ridging; TRF – tractor trail furrow with tied ridging. The distance between potato rows (centres of ridges) for F and RF variants was 0.75 m, for TF and TRF variants it was 1.05 m. Before planting, de-stoning was always performed. Each year, the two-row Reekie RBM-2HP potato planter (Boston, UK) was used, equipped with tied-ridging equipment, which made reservoirs at intervals of 0.5 m; they were 0.4 m long, 0.25 m wide with a volume of 2 L. The planting always proceeded directly down the gradient. The experimental rows were separated by a 10 m metal barrier to a depth of at least 0.4 m so that the surface runoff from the outside area did not affect the measured area. At the bottom end of the test area, collectors were placed with collecting tanks to capture the surface runoff from the furrows as shown in Figure 1. The collectors were placed so that they would span from the centre of one ridge to the centre of the next, leaving no gaps between them. In total, 12 collecting tanks (3 furrows for each variant) were installed. The method of capturing the surface water runoff was based on Olivier et al. (2014). The water balance was calculated from the area which was 54 m^2 for the sum of variants with tied ridging and 54 m^2 for the sum of control variants. For centre furrow variants, the area was 22.5 m^2 (3 × 7.5 m^2), and for tractor trail furrows, it was 31.5 m^2 (3 × 10.5 m^2). During the study, precipitation was recorded by the AMET MeteoUNI weather station (Velké Bílovice, Czech Republic) with a resolution of 0.3 mm.

In 2014, the experiment was established on April 25 when planting took place, on June 4 the plants emerged and after 91 days the foliage has died off. The surface runoff monitoring was terminated on

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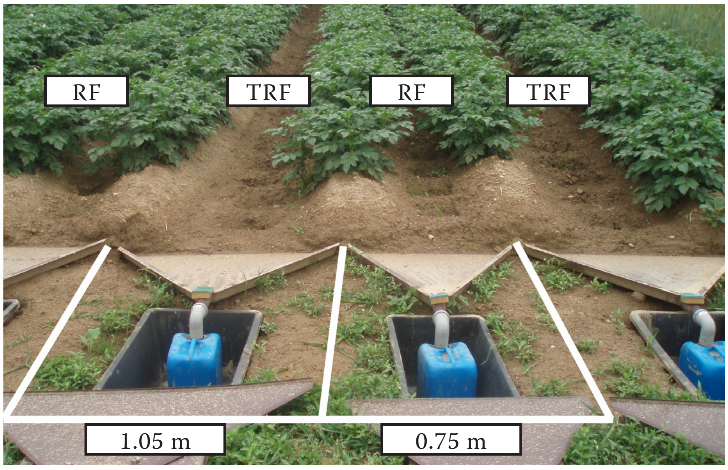

Figure 1. Collectors and tanks were placed at the bottom end of rows; picture shows the RF (centre furrow with tied ridging) and TRF (tractor trail furrow with tied ridging) variants

October 3 with subsequent harvesting on October 9. In 2015, the planting took place on May 5. The growing period lasted 112 days from shoot emergence on June 10. The harvest and runoff monitoring was terminated on November 11. In the last experiment year 2016, the planting took place on May 9. From the emergence of the shoots on June 9, the growing period lasted 101 days. The end of sampling of surface runoff was on September 19, and harvest took place on September 27. The dates were chosen according to the agrotechnical requirements for each given year. The water runoff collected from the test plots was periodically emptied from the collecting tanks, and the volume was determined. The time and frequency of such sampling of the surface runoff in each year were chosen based on actual rainfall events about the capacity of the collecting tanks. Determination of yields was carried out each year using a potato plough followed by a manual collection of the tubers. Weight was measured by the KERN DE 150K50N balances (Balingen, Germany). The yields were determined from individual rows and those that were between tied-ridging furrows (RF + TRF) were compared with the control (F + TF).

The seasonal data were evaluated with help of the Statistica 12CZ software (Palo Alto, USA) at the 0.95 confidence level. The significance of the effect of tied ridging treatment on surface runoff reduction was evaluated using the Kruskal-Wallis test and for comparison of control (F + TF) with tied-ridging furrows (RF + TRF) the Mann-Whitney U test was used. The t-test was then used to determine the significance of the effect of tied ridging on tuber yield.

RESULTS AND DISCUSSION

In 2014, the total rainfall for the monitoring season from April 25 to September 3 was 456 mm, resulting in 19 sampling periods listed in Table 1 together with precipitation sums. It is worth noting that an extreme precipitation event was recorded in the

Table 1. Sampling periods during the 2014 season with the total precipitation and maximum precipitation intensity in a day and 15 min

Sampling period	25.4.–4.5.	5.5.–13.5.	14.5.–19.5.	20.5.–25.5.	26.6.–27.6.	28.5.–3.6.	4.6.–25.6.	26.6.–30.6.	1.7.–6.7.	7.7.–10.7.	11.7.–16.7.	17.7.–23.7.	24.7.–3.8.	4.8.–24.8.	25.8.–28.8.	29.8.–2.9.	3.9.–10.9.	11.9.–14.9.	15.9.–3.10.
Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Total precipitation (mm)	31.3	18.9	33.9	16.9	27.2	16.0	22.1	15.3	12.8	17.3	14.4	10.9	18.5	28.5	21.1	63.7	8.0	42.5	36.8
Maximum daily precipitation (mm)	15.7	7.0	19.5	16.3	26.9	15.7	18.9	7.3	12.8	16.6	14.4	9.6	13.1	7.0	15.3	29.4	8.0	17.3	11.8
Maximum precipitation intensity (mm/15 min)	5.4	1.3	1.6	3.5	10.9	0.9	3.2	2.2	3.8	5.4	5.4	1.6	1.6	2.2	1.9	10.9	5.4	3.5	3.2

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Table 2. Sampling periods during the 2015 season with the total precipitation and maximum precipitation intensity in a day and 15 min

Sampling period	5.5.–13.5.	14.5.–24.5.	25.5.–4.6.	5.6.–11.6.	12.6.–15.6.	16.6.–22.6.	23.6.–9.7.	10.7.–27.7.	28.7.–18.8.	19.8.–9.9.	10.9.–11.10.
Sample No.	1	2	3	4	5	6	7	8	9	10	11
Total precipitation (mm)	20.1	20.5	12.5	18.2	26.2	19.2	10.5	14.1	88.0	38.7	13.4
Maximum daily precipitation (mm)	11.2	15.7	7.0	18.2	16	10.9	6.7	6.7	48.6	14.4	6.7
Maximum precipitation intensity (mm/15 min)	1.6	0.9	3.8	2.9	5.4	3.8	4.1	1.6	11.5	3.8	1.3

5th period when the maximum daily rainfall was 26.9 mm with a maximum intensity of 10.9 mm in 15 min and in the 16th period when the maximum daily rainfall was 29.4 mm with maximum intensity also nearly 11 mm/15 min. During these two events, the reservoirs were effectively destroyed. After the first event, the reservoirs were restored to their full capacity, as the foliage was not developed yet and would not be damaged. In the second test year, 2015, the total rainfall for the season from May 5 to November 11 amounted to only 281.4 mm, and the highest daily amount was recorded in the 9th period at 48 mm with a maximum intensity of 11.5 mm in 15 min. The second year was divided into 11 sampling periods, as shown in Table 2. In the last year, the total precipitation measured for the season from planting to the last sampling on September 19 was 249.7 mm and the season was divided into 12 sampling periods (Table 3).

All reservoirs showed mild sedimentation and decreased efficiency over time, which corresponds to Olivier et al. (2014). The filling of the reservoirs with sediment was always more pronounced before foliage development, which is caused by the amount of soil particle spray decreasing exponentially with increasing coverage by the crop as explained by Mati (1994). This mostly includes the soil that is drifting from the side walls of the ridges to the bottom of the furrow. Based on this, it can be recommended to restore the reservoirs before foliage development which will increase the overall efficiency of the tied-ridging method throughout the vegetation period (Vejchar et al. 2017). This was confirmed in the 2015 season, where, among other things, the overall efficiency of the tied ridging method decreased due to the absence of reservoir restoration.

In 2016, just before the complete foliage development, the reservoirs were restored. In contrast to the previous years, there was no breach of the dams between reservoirs from the stage of foliage development until the end of the monitoring season. Although in the 16th sampling period of 2014 and the 9th sampling period of 2015, the reservoirs were largely filled with sediment and the dams were breached through. During the subsequent periods, they still retained 49% and 55% more water on the land, respectively, in the case of combined tied-ridging variants over the control.

The total water savings captured by tied-ridging treatment are considerable as shown in Tables 4 and 5

Table 3. Sampling periods during the 2016 season with the total precipitation and maximum precipitation intensity in a day and 15 min

Sampling period	9.5.–16.5.	17.5.–30.5.	31.5.–5.6.	6.6.–15.6.	16.6.–21.6.	22.6.–27.6.	28.6.–14.7.	15.7.–24.7.	25.7.–29.7.	30.7.–31.7.	1.8.–22.8.	23.8.–19.9
Sample No.	1	2	3	4	5	6	7	8	9	10	11	12
Total precipitation (mm)	18.3	11.5	10.7	27.1	7.9	23.9	56.0	15.0	20.2	20.4	23.5	15.2
Maximum daily precipitation (mm)	12.1	9.3	7.2	18.2	6.0	16.9	31.6	15.0	12.2	20.4	13.2	5.7
Maximum precipitation intensity (mm/15 min)	5.8	7.0	1.0	5.1	1.0	2.0	2.0	2.5	6.0	6.4	2.5	2.5

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Table 4. Total surface water runoff in all variants over seasons

Variant	2014		2015		2016	
	Total surface runoff over season (mm)	Relative decrease in runoff with tied ridging treatment (%)	Total surface runoff over season (mm)	Relative decrease in runoff with tied ridging treatment (%)	Total surface runoff over season (mm)	Relative decrease in runoff with tied ridging treatment (%)
RF	8.0^{a}	71.0	9.8^{a}	67.7	6.8^{a}	86.2
F	27.6^{b}		30.4^{b}		49.0^{b}	
TRF	9.6^{a}	67.7	21.4^{ab}	24.4	13.8^{a}	72.4
TF	29.7^{b}		28.3^{b}		50.2^{b}	
P-value	< 0.000001	–	0.0012	–	< 0.000001	–

Values of significantly different groups are marked by different letters according to the Kruskal-Wallis test with following non-parametric post-hoc comparison at the 0.95 significance level. RF – centre furrow with tied ridging; F – centre furrow; TRF – tractor trail furrow with tied ridging; TF – tractor trail furrow

and Figure 2. In the year 2014, in the variants RF + TRF 69% of the runoff was prevented compared to the control F + TF. In 2016, the saving was even 78%. In TRF, the efficiency was always lower than in RF, which is explained by the fact that the dimensions of the reservoirs produced in the TRF are the same as for the RF, whereas the area of TRF was greater. In the year 2016, the RF variant retained by 86% more water in the field compared to F. Olivier et al. (2014) carried out similar studies in Belgium on 30 m long plots with small reservoirs at 1.6 m intervals. They monitored the efficiency in various rainfall events from May to September and found runoff decreased by 85% until a 40 mm rainfall event in August.

In the experiments carried out, the reduction in a surface runoff with tied ridging in rows of potatoes could be confirmed at a significance level of 0.95 using the Kruskal-Wallis test and to compare the control (F + TF) with tied-ridging furrows (RF + TRF), the Mann-Whitney U test was used. Figure 2 shows average values and confidence intervals for each year and all variants.

The use of tied ridging appears to be an effective method in de-stoned soils, where the runoff from untreated furrows (F + TF) was 1.7 to 4 times higher in the tested seasons compared to furrows with tied ridging (RF + TRF). This complements a study by Chow et al. (1992), which confirms higher susceptibility of the stone separated soils to surface water runoff by a factor of 1.4 to 1.7 compared to unseparated soils in potato production.

The secondary objective was to test the effect of tied ridging on the yield of tubers. It was apparent during the test years that better water retention in furrows created good conditions to increase the yield (Table 6). The RF + TRF variants in 2014 resulted in an increase in the yield by 4.6%, or 1.5 t/ha compared to F + TF. In 2016 the RF + TRF had more than 8% higher yield over the F + TF control which produced 43.8 t/ha. However, the observed values

Table 5. Average surface water runoff in variants of control (F + TF) and with tied-ridging furrows (RF + TRF) over seasons

Variant	2014		2015		2016	
	Total surface runoff over season (mm)	Relative decrease in runoff with tied ridging treatment (%)	Total surface runoff over season (mm)	Relative decrease in runoff with tied ridging treatment (%)	Total surface runoff over season (mm)	Relative decrease in runoff with tied ridging treatment (%)
RF + TRF	8.9	69.1	16.6	43.2	10.9	78.1
F + TF	28.8		29.2		49.7	
P-value	< 0.000001	–	0.000212	–	< 0.000001	–

The Mann-Whitney *U* test was used to test the non-parametric comparison at the 0.95 significance level. RF – centre furrow with tied ridging; TRF – tractor trail furrow with tied ridging; F – centre furrow; TF – tractor trail furrow

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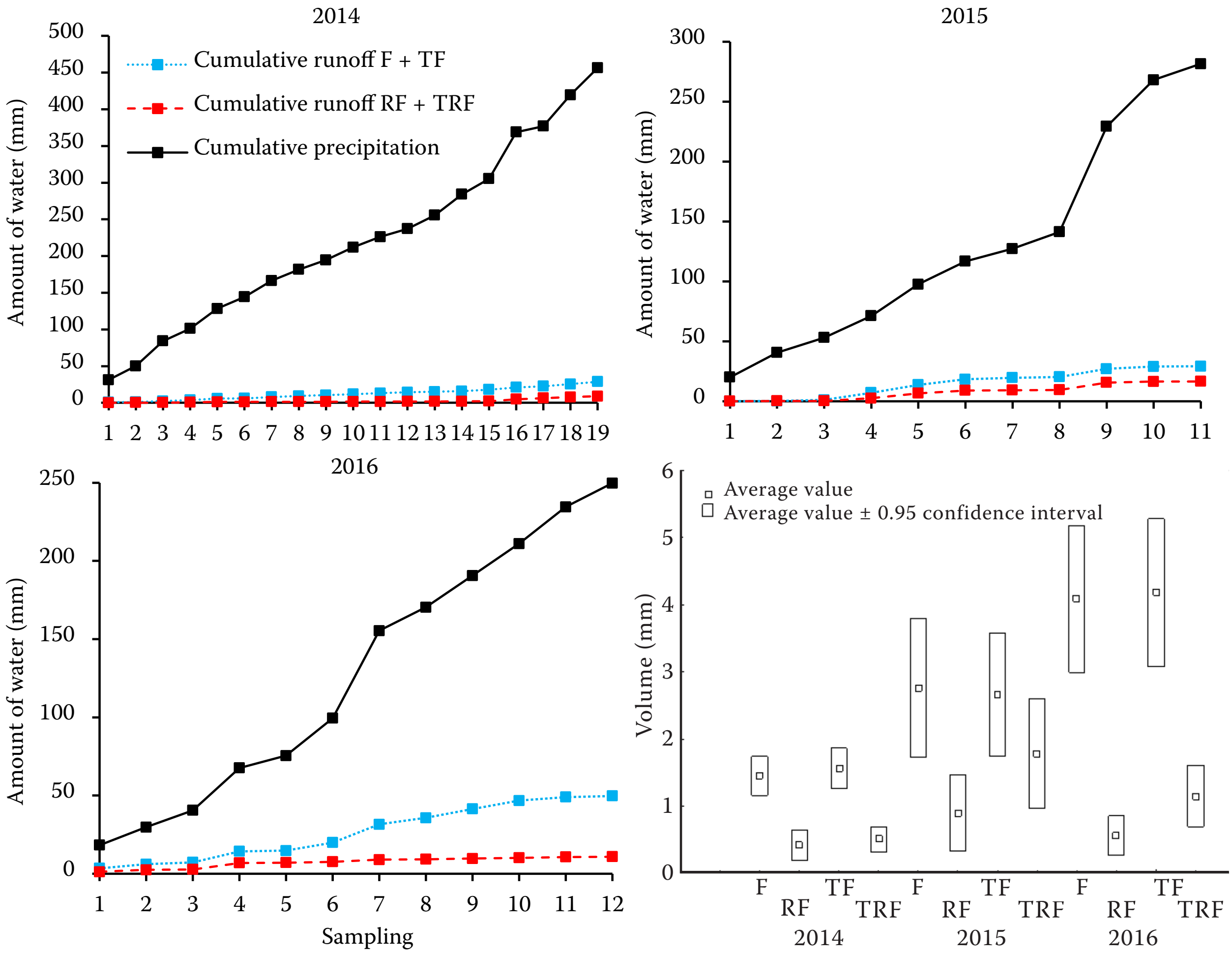

Figure 2. Cumulative precipitation and surface runoff during the monitored seasons. Bottom right: average runoff during one sampling period and its 95% confidence interval. F – centre furrow; TF – tractor trail furrow; RF – centre furrow with tied ridging; TRF – tractor trail furrow with tied ridging. Similar results from a 2016 one-year experiment were published in Vejchar et al. (2017)

could not statistically prove the effect of tied ridging on yield at 0.05 uncertainty level. In recent years, the tied ridging technology (Agassi and Levy 1993) in Israel increased yields in two years out of the three tested by up to 18%, whereas (Olivier et al. 2014) achieved a yield increase of over 7%, however statistically inconclusive.

In 2015, tied-ridging technology achieved only a 1.8% higher yield, and an increased incidence of deformed tubers by secondary potato tuberization

Table 6. Potato tuber yields from the tested plots, combined variants F + TF vs. RF + TRF

Variant	2014		2015		2016	
	Potato tuber yield (t/ha)	Increase in yield with tied ridging treatment (%)	Potato tuber yield (t/ha)	Increase in yield with tied ridging treatment (%)	Potato tuber yield (t/ha)	Increase in yield with tied ridging treatment (%)
RF + TRF	35.0	4.6	44.9	1.8	47.4	8.1
F + TF	33.5		44.1		43.8	
P-value	0.0793		0.6957		0.1011	

The *P*-values represent the results of *t*-test. RF – centre furrow with tied ridging; TRF – tractor trail furrow with tied ridging; F – centre furrow; TF – tractor trail furrow

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in the TF + TRF variant was also observed. Between July 18th and August 15th in that year, the plants were noticeably damaged by heat stress, during which 9 rainfall events were recorded with a total rainfall of 7 mm. The drought ended with three-day rainfall, and growth increased markedly in the RF + TRF variant. Possible reasons for the fluctuation in yield and presence of secondary tuberization could be explained by the study of Rykaczewska (2017), who showed that the tested reaction of potato cultivars to heat stress depended on the stadium of growth in which the temperature affects the plants and on the soil moisture. In addition to decreasing yields and reducing the number of tubers, the greatest problem was the presence of tubers with physiological defects.

REFERENCES

Agassi M., Levy G.J. (1993): Effect of the dyked furrow technique on potato yield. Potato Research, 36: 247–251.

Alva A.K., Hodges T., Boydston R.A., Collins H.P. (2002): Effects of irrigation and tillage practices on yield of potato under high production conditions in the Pacific Northwest. Communications in Soil Science and Plant Analysis, 33: 1451–1460.

Čepl J., Kasal P. (2001): Effects of various ways of pre-plant soil preparation on potato tuber yields and soil physical properties and soil temperature. Rostlinná Výroba, 47: 475–481.

Chow T.L., Rees H.W., Moodie R.L. (1992): Effects of stone removal and stone crushing on soil properties, erosion, and potato quality. Soil Science, 153: 242–249.

Edwards L.M., Volk A., Burney J.R. (2000): Mulching potatoes: Aspects of mulch management systems and soil erosion. American Journal of Potato Research, 77: 225–232.

Gordon R.J., Vanderzaag A.C., Dekker P.A., De Haan R., Madani A. (2011): Impact of modified tillage on runoff and nutrient loads from potato fields in Prince Edward Island. Agricultural Water Management, 98: 1782–1788.

Kovář P., Vaššová D., Janeček M. (2012): Surface runoff simulation to mitigate the impact of soil erosion, case study of Třebsín (Czech Republic). Soil and Water Research, 7: 85–96.

Mati B.M. (1994): Splash transport of soil on a slope under various crop covers. Agricultural Water Management, 26: 59–66.

Mu W.B., Yu F.L., Li C.Z., Xie Y.B., Tian J.Y., Liu J., Zhao N.N. (2015): Effects of rainfall intensity and slope gradient on runoff and soil moisture content on different growing stages of spring maize. Water, 7: 2990–3008.

Munodawafa A. (2007): Assessing nutrient losses with soil erosion under different tillage systems and their implications on water quality. Physics and Chemistry of the Earth, Parts A/B/C, 32: 1135–1140.

Nuti R.C., Lamb M.C., Sorensen R.B., Truman C.C. (2009): Agronomic and economic response to furrow diking tillage in irrigated and non-irrigated cotton (*Gossypium hirsutum* L.). Agricultural Water Management, 96: 1078–1084.

Olivier C., Goffart J.P., Baets D., Xanthoulis D., Fonder N., Lognay G., Barthélemy J.P., Lebrun P. (2014): Use of micro-dams in potato furrows to reduce erosion and runoff and minimise surface water contamination through pesticides. Communications in Agricultural and Applied Biological Sciences, 79: 513–524.

Rulfová Z., Beranová R., Kyselý J. (2017): Climate change scenarios of convective and large-scale precipitation in the Czech Republic based on EURO-CORDEX data. International Journal of Climatology, 37: 2451–2465.

Rykaczewska K. (2017): Impact of heat and drought stresses on size and quality of the potato yield. Plant, Soil and Environment, 63: 40–46.

Silva L.L. (2017): Are basin and reservoir tillage effective techniques to reduce runoff under sprinkler irrigation in Mediterranean conditions? Agricultural Water Management, 191: 50–56.

Sui Y., Ou Y., Yan B., Xu X., Rousseau A.N., Zhang Y. (2016): Assessment of micro-basin tillage as a soil and water conservation practice in the black soil region of Northeast China. PLoS One, 11: e0152313.

Truman C.C., Nuti R.C. (2009): Improved water capture and erosion reduction through furrow diking. Agricultural Water Management, 96: 1071–1077.

Truman C.C., Nuti R.C. (2010): Furrow diking in conservation tillage. Agricultural Water Management, 97: 835–840.

Vejchar D., Stehlik M., Mayer V. (2017): Influence of tied ridging technology on the rate of surface runoff and erosion in potato cultivation. Agronomy Research, 15: 2207–2216.

Xia L.Z., Liu G.H., Ma L., Yang L.Z., Li Y.D. (2014): The effects of contour hedges and reduced tillage with ridge furrow cultivation on nitrogen and phosphorus losses from sloping arable land. Journal of Soils and Sediments, 14: 462–470.

Received on November 12, 2018
Accepted on January 25, 2019
Published online on February 8, 2019