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The influence of a system with permanent traffic lanes on physical properties of soil, soil tillage quality and surface water runoff

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Abstract. The system with permanent driving tracks at the module of machines working width 6 metres, practised in a 10-ha field, allowed to consistently separate the area designed for restricted traffic lanes of farm machines from the production area of the field. The aim of the study is to assess the selected indicators of the condition of topsoil, which is characterized by soil porosity, indicators of soil workability, soil ability to absorb water from rainfall and soil loss by wash after four years of controlled traffic system application in a field trial. Indicators of soil condition were evaluated in four variants with different wheel impacts of tractors and other machines on the soil. A field trial was established in the spring 2010; the measured values in the study are from 2013 and 2014. The results show an advantage, which represents concentration of passages into permanent tracks aimed at protection of most part of a plot from soil compaction. Hardness of clods after tillage in autumn 2013 was five times higher in places with random traffic (356.7 kPa) than outside traffic lanes in the system of controlled traffic (70 kPa). An important result is that the system with permanent traffic lanes made it possible to increase the soil capacity of taking up water under intensive rainfall – in comparison to a part of the land with random passes. The results of measurements with a rainfall simulator in April 2014 showed that cumulative surface runoff after sixty minutes was 7.6 l m^{-2} on the land with random passes while 3.9 l m^{-2} outside the traffic lanes (32% of the area of the field). The soil loss by wash during water surface runoff was also lower with controlled traffic compared to the variant with random passes. Therefore it is to assume that suitable application of the controlled traffic farming system may be a contribution to soil protection from water erosion.

Key words: soil compaction, controlled traffic farming, surface water runoff, water erosion.

INTRODUCTION

The wheel traffic of tractors, conveyances, fertilizer and pesticide distributors, harvesters, implements and trucks causes soil compaction. The soil has different resistance to compression. Crucial factors are soil texture, instantaneous soil moisture, content of organic compounds in the soil and soil structure. One of the consequences of undesirable soil compaction is the increased energy requirement for its primary and secondary cultivation.

Technogenic soil compaction cannot be eliminated but it is possible to significantly contribute to a reduction in its intensity. One of the possibilities is to confine the necessary wheel traffic in fields to permanent tracks in order to ensure that a major part of the production area of fields will remain without the negative influence of wheel traffic (Chamen et al., 2003; Tullberg, 2010). A system with permanent tracks is called Controlled Traffic Farming (CTF). This system can be used in practical farming conditions due to the existence of precise navigation systems in combination with the automated steering of tractors and other machines passing in fields. A contribution of the CTF system is a reduction in the rolling resistance of wheels, and also lower energy requirement for soil tillage if the major part of the field area is without soil compression by wheels or tracks of machines (Kroulík et al., 2011; Tullberg et al., 2007).

In compacted soils there is a substantially lower rate of infiltration for water especially under intensive rainfall. Yuxia et al. (2001) reported for the uncompacted soil a four to five times higher rate of infiltration than in the soil compacted by wheel traffic. These authors also documented that soil compaction has a greater influence on the rate of water infiltration into the soil than soil tillage. According to Li et al. (2004) the losses of the area by wheel tracks can be compensated by higher yield.

The issues of controlled traffic are known. The aim of the field experiment was to clarify the differences in the state of topsoil after several years of use of the system with permanent traffic lanes and compare selected soil properties with parts of field with random traffic.

It turns out that not only physical soil properties and indicators of soil workability shall be evaluated, but it is relevant to evaluate as well the indicators of risk of water erosion. These include surface water runoff and soil loss by wash.

MATERIALS AND METHODS

A field trial on a land of 10 ha in size was established in spring 2010. Soil conditions: loamy soil (content of particles smaller than 0.01 mm in the topsoil layer: 38.3% by weight). Content of carbon in topsoil: 3.8%.

After medium-deep soil tillage to a depth of 0.25 m (Horsch Tiger 4MT, October 15, 2009) the field remained without wheel traffic until spring 2010, when wheel traffic was organised within the CTF system using OutTrac (Chamen, 2006) – Fig. 1. On this field the soil properties were evaluated in four variants of wheel effect:

1. Traffic lanes of tractors during sowing, application of chemicals for plant protection, application of mineral fertilizers, lanes of tractors during soil tillage – repeated 10 times, working width 18 m.
2. Traffic lanes of wheels of a tractor during sowing, lanes of a combine harvester and lanes of a tractor during soil tillage (without lanes of tractors at chemicals for plant protection and mineral fertilizers application) – repeated 30 times, working width 6 m.
3. Outside the traffic lanes.
4. Part of the field with uncontrolled wheel traffic (area of 3 ha) – Random – repeated 12 times, the traffic lanes were moved every year.

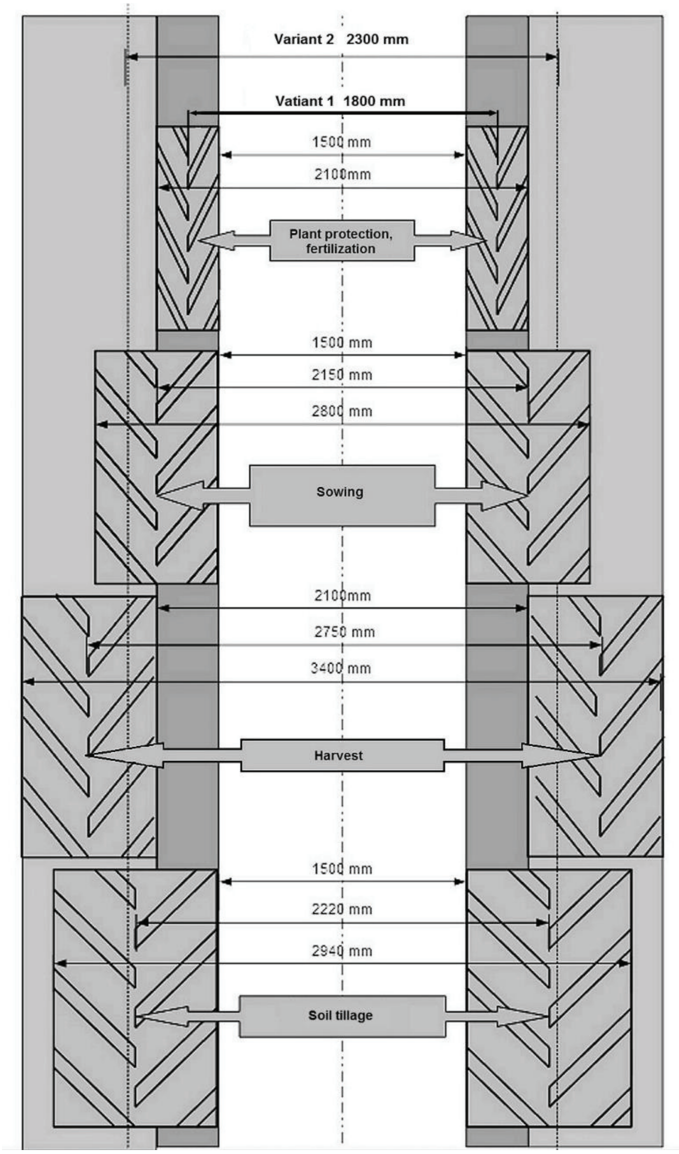

Figure 1. Wheel ruts of tractors and combine harvester after their concentration to permanent traffic lanes.

In the variants of the field trial measurements basic physical properties of soil were evaluated. Spatial distribution of soil particles was evaluated by means of undisturbed soil samples taken into Kopecky´s rings (100 cm^3). The samples were processed in the standard way and soil bulk density, total porosity and moisture content was determined (Valla et al., 2008). Undisturbed soil samples were taken from a depth of 0.05 to 0.10 m, 0.15 to 0.20 m, 0.25 to 0.30 m and 0.35 to 0.40 m. Samples were always in five replications.

After soil tillage process the topsoil from the area of 0.25 m^2 was collected from a depth of 0 to 0.10 m and sieved on sieves with square openings of 100 mm, 50 mm, 30 mm and 10 mm (three repetitions). Individual fractions were weighed and calculated the proportion of fractions in weight percent. For the measuring of penetration resistance of surface soil layer and penetration resistance of clods after soil tillage it was used the pocked penetrometer Ejkelkamp with cylindrical body (foot diameter 6.35 mm, depth of pushing the cylinder: 6.35 mm).

This paper contains the results of evaluation of wheel traffic impacts on the soil in a field trial in 2013 (the fourth year of the consistent application of controlled traffic farming in a field). Measurements by the rain simulator were held in April 2014.

Surface water runoff was measured under simulated sprinkling on a measurement area of 0.5 m^2 in size and at rainfall intensity of 87.8 mm h^{-1}, using three replications for each treatment. Infiltration rate is determined from the defined rainfall intensity that is constant for the time of measurement and from surface runoff of water from the measurement area (Kovaříček et al., 2008). Intercepted water from surface runoff is filtered, quantity of filtered soil is dried up and from the dry weight of washed soil the unit loss of soil (g m^{-2} h^{-1}) caused by water erosion is determined (the average sample).

For basic data processing was used software MS Excel 2010. It was also used STATISTICA CZ software version 12 (StatSoft) for graphic processing of the resulting values and the statistical analysis ANOVA with Tukey HSD test –homogeneous groups test ($\alpha = 0.05$).

For the navigation of machines during soil tillage, sowing, application of chemicals for plant protection, application of mineral fertilizers and during harvest a GPS satellite system with the correction signal of RTK VRS was used. For machines steering an assisted steering system AgGPS EZ-STEER (Trimble) was used. Table 1 documents field operations and machines used for work operations.

Table 1. Field operations and machines (2013/2014)

Field operation	Machines	Working width (m)	Distance of tracks (mm)	Tyre width (mm)
Sowing of winter wheat (18.10.2012)	NEW HOLLAND + VÄDERSTAD Rapid 600P	6	2,150	500 x 2
Mineral fertilizers application (19.3.2013)	ZETOR 10145 + AMAZONE 1000	18	1,800	300 x 2
Pesticide application (27.4.2013)	CASE JX 1100U + AGRIO NAPA 18	18	1,800	320 x 2
Pesticide application (11.6.2013)	CASE JX 1100U + AGRIO NAPA 18	18	1,800	320 x 2
Winter wheat harvest (2.8.2013)	CLAAS Lexion 460	6	2,750	650 x 2
Shallow loosening, 0.08–0.10 m (4.8.2013)	CASE 335 + FARMET Hurikan 600	6	2,220	720 x 2
Medium deep loosening, 0.14–0.16 m (15.11.2013)	CASE 335 + Simba SLD 600	6	2,220	720 x 2
Sowing of spring pea (7.4.2014)	NEW HOLLAND + VÄDERSTAD Rapid 600P	6	2,150	500 x 2
Pesticide application (26.4.2014)	CASE JX 1100U + AGRIO NAPA 18	18	1,800	320 x 2

Weather data of experimental years are in Table 2.

Table 2. Weather data of experimental years

Year	Month	Air temperature (°C)	Total precipitation (mm)
2013	1	1.7	18.8
	2	2.8	10.8
	3	3.0	15.2
	4	9.8	35.4
	5	13.7	70.4
	6	17.6	145.0
	7	21.4	26.8
	8	19.4	10.2
	9	13.6	0.2
	10	10.2	47.7
	11	5.4	17.5
	12	2.6	7.2
2014	1	1.5	22.0
	2	3.2	1.4
	3	7.7	29.0
	4	11.3	8.8

RESULTS AND DISCUSSION

In the fourth year of the field trial, in 2013, physical properties of soil were determined at sites with different intensity of the wheel traffic action on soil (variants 1 to 4). Graph in Fig. 2 show total porosity of soil in the topsoil layer. Before winter wheat harvest, as expected the highest soil porosity was found out at sites without wheel tracks (variant 3) while the values of soil porosity were lowest in variant 1 with the highest intensity of wheel traffic. At a depth of 0.35–0.40 m there were no larger differences in the values of soil porosity between the variants any more – average values of total porosity: 38.9 (Var. 1), 38.3 (Var. 2), 38.6 (Var. 3), 39.5 (Var. 4). Confirmed the results of previous years: in the CTF system were favorable indicators of soil physical properties on the most area of field. This is consistent with the results of McHugh et al., (2009) whereby controlled traffic is an opportunity for restoration of physically degraded soil after random field wheeling. According Hamza & Anderson (2005) increasing of soil porosity is a tool of reduction even elimination of soil compaction. We prefer the use of controlled traffic but further measures can be recommended: addition of organic matter, selecting appropriate crop rotation, suitable mechanical loosening.

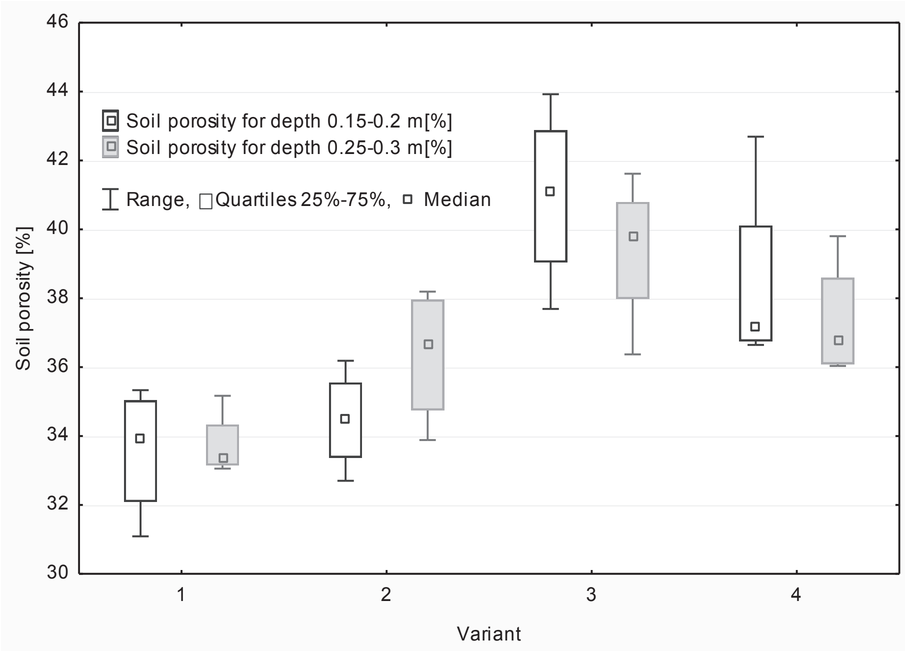

Figure 2. Total porosity of soil at a depth of 0.15–0.20 m and 0.25–0.30 m (2nd July. 2013). Variants: 1 – Traffic lanes including application of chemicals for plant protection and mineral fertilizers; 2 – Traffic lanes without application of chemicals for plant protection and mineral fertilizers; 3 – Outside the traffic lanes; 4 – Random traffic.

Fig. 3 illustrates the values of the surface soil layer resistance to the penetration of the cylindrical body of a penetrometer. On the summer date of measurement differences in the values between variants 1, 2 and 4 were statistically insignificant while penetration resistance in the variant without wheel traffic (variant 3) was statistically significantly lower than in all the other three variants (Tukey HSD test). A similar conclusion was drawn for the statistical significance of differences in penetration resistance measured during the crumbling of clods that originated by autumn soil tillage. The distinctly lowest resistance of clods to crumbling at sites without long-time wheel traffic is shown in Fig. 4. At sites without passes the topsoil crumbling was good without formation of large clods (variant 3) – Fig. 5. On the contrary, at sites with concentrated wheel tracks (variants 1 and 2), and also at sites with random wheel traffic, large clods were formed that are undesirable for the quality of sowing of subsequent winter crop. On an experimental land the area without wheel tracks accounted for 68% of the area of this land. At random machinery traffic 86.1% of the total field area was run-over at least once a year, when using conventional tillage for winter wheat, and 63.8% of the total field area was run-over when using conservation tillage (Kroulík et al., 2011).

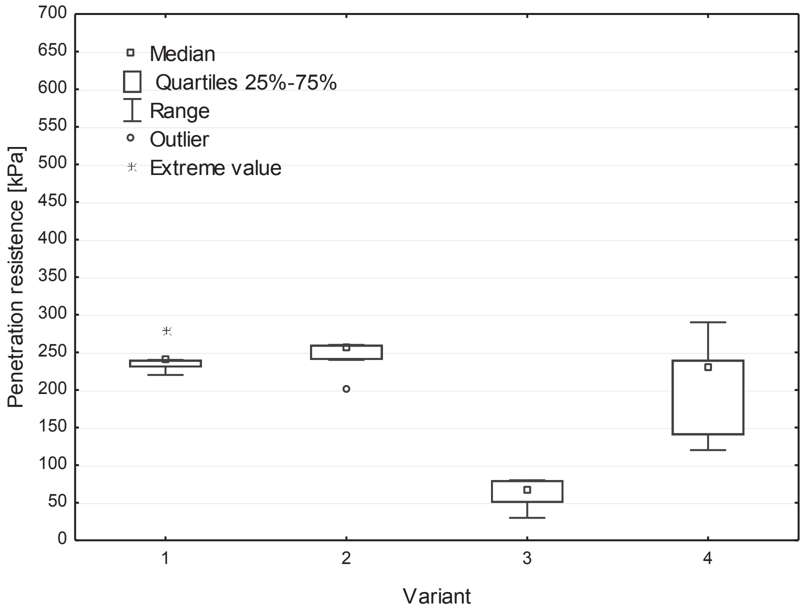

Figure 3. Penetration resistance at a depth of 0.05 m (2nd July. 2013) – soil moisture content (weight%): 18.7 (Var. 1), 20.1 (Var. 2), 19.6 (Var. 3), 20.1 (Var. 4). Variants: 1 – Traffic lanes including application of chemicals for plant protection and mineral fertilizers; 2 – Traffic lanes without application of chemicals for plant protection and mineral fertilizers; 3 – Outside the traffic lanes; 4 – Random traffic.

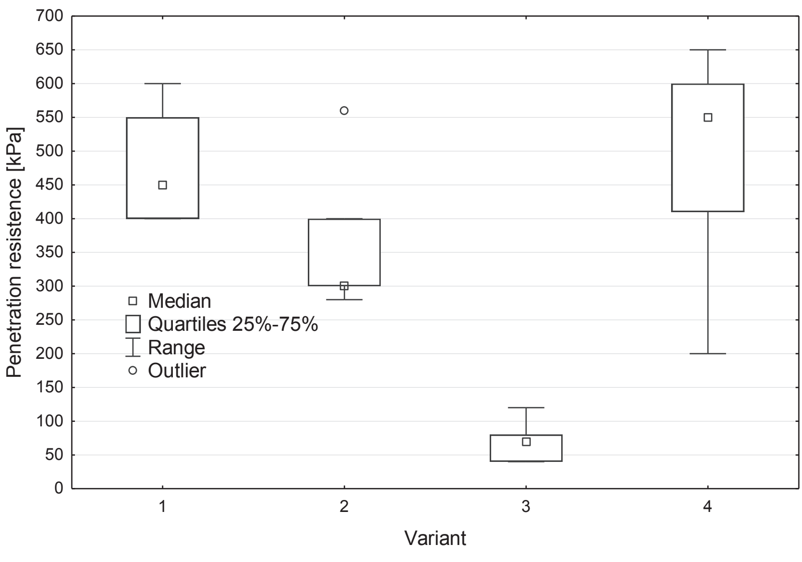

Figure 4. Penetration resistance of clods (31st October 2013) – soil moisture content (weight%): 18.4 (Var. 1), 18.2 (Var. 2), 20.8 (Var. 3), 17.1 (Var. 4). Variants: 1 – Traffic lanes including application of chemicals for plant protection and mineral fertilizers; 2 – Traffic lanes without application of chemicals for plant protection and mineral fertilizers; 3 – Outside the traffic lanes; 4 – Random traffic.

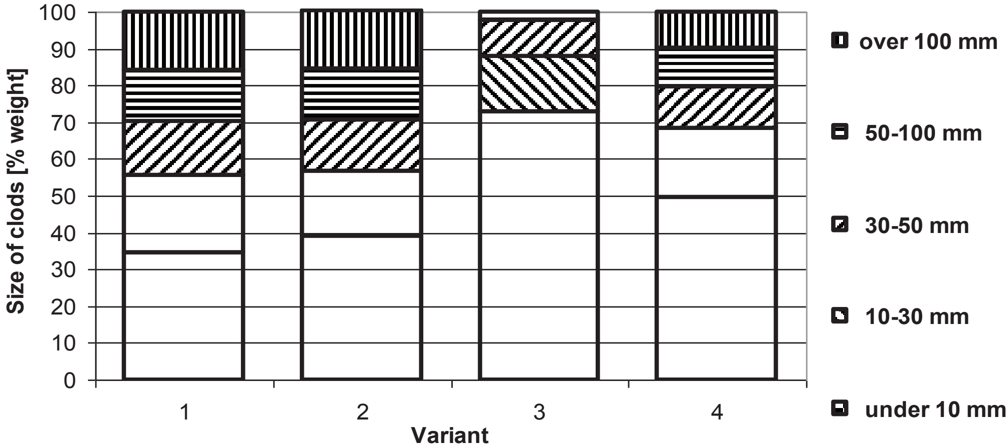

Figure 5. Size of clods after loosening (0–0.10 m) (31st October 2013). Variants: 1 – Traffic lanes including application of chemicals for plant protection and mineral fertilizers; 2 – Traffic lanes without application of chemicals for plant protection and mineral fertilizers; 3 – Outside the traffic lanes; 4 – Random traffic.

It is to assume that differences in physical properties of soil and quality of soil tillage can be reflected in different capacity of the soil to take up water under intensive rainfalls. The results of measurements with a rainfall simulator in April 2014, after four years from the beginning of the field trial, are documented in Fig. 6. The graph shows a surface runoff under artificial rainfall made at a rate of 88 l m^{-2} h^{-1}, which is 88 mm of rainfall per hour. Surface runoff at sites with confined wheel traffic to permanent tracks (variants 1 and 2) and on a part of the land with random passes (variant 4) was substantially different from variant 3. An important indicator is the onset of surface runoff. In variant 3 (outside the wheel tracks) surface runoff began in almost 40 minutes from the beginning of artificial rainfall, until then all water was infiltrated into the soil. At sites with permanent wheel tracks, and also at sites with random passes, surface runoff started within a more than twice shorter time than on the land without lanes. This result is consistent with the conclusions drawn by Yuxia et al., (2001) and Li et al., (2004). The results of measurements with a rainfall simulator indicate a contribution of the controlled traffic farming technology to the improved capacity of soil to take up water under intensive rainfall.

Surface runoff water is related with a risk of soil erosion. Fig. 7 shows the soil loss by wash under artificial rainfall. The measurement with a rainfall simulator showed the highest soil loss by wash in variant 4 (random passes) – 24.9 g m^{-2} h^{-1}. The almost tenfold lower soil loss was observed at sites without wheel traffic. The low soil loss by wash was also measured at a site of permanent tracks (variant 1). This result supports a hypothesis about the contribution of a system with permanent traffic lanes to a reduction in the water erosion of soil.

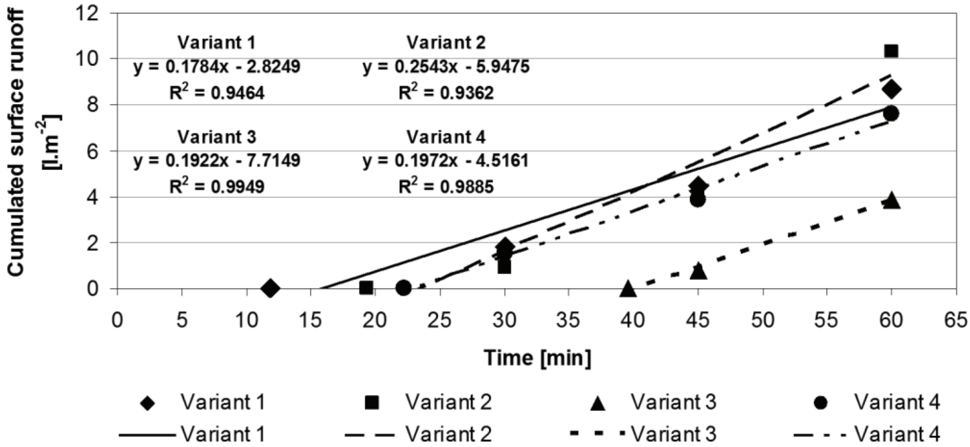

Figure 6. Cumulative surface runoff under artificial rainfall (rainfall simulator) – 29th April 2014, four years after the founding of the field experiment (*x* – time, *y* – cumulative surface runoff). Variants: 1 – Traffic lanes including application of chemicals for plant protection and mineral fertilizers; 2 – Traffic lanes without application of chemicals for plant protection and mineral fertilizers; 3 – Outside the traffic lanes; 4 – Random traffic.

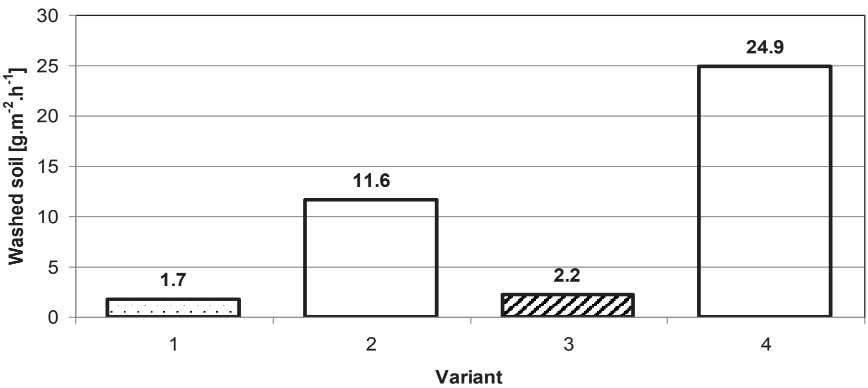

Figure 7. Soil loss by wash under artificial rainfall – 29th April 2014. Variants: 1 – Traffic lanes including application of chemicals for plant protection and mineral fertilizers; 2 – Traffic lanes without application of chemicals for plant protection and mineral fertilizers; 3 – Outside the traffic lanes; 4 – Random traffic.

The results of measurements of water surface runoff under artificial rain made with a rainfall simulator are consistent with the results of the authors who evaluated the influence of soil compaction on water infiltration into the soil (Hamza & Anderson, 2005; Raper & Kirby, 2006). Crop residues have a great importance on the soil surface. According to Tullberg (2010) maximum runoff and soil loss occurred on compacted, non-tilled plots unprotected by plant residues. For this reason, it is appropriate to keep the crop residues in place of traffic lanes for the benefit of erosion control measures.

It shows that a major barrier to adoption of controlled traffic farming in practice is the lack of compatibility in equipment as reported Tullberg (2010).

CONCLUSIONS

The results of evaluation of physical properties of soil four years after the establishment of a field trial indicated favourable physical properties of soil on a part of the field without wheel tracks – the area without wheel tracks accounted for 68% of the land area when the working width module of 6 m was used. The work quality of machines for soil tillage operations was also higher on a part of the field without wheel tracks. An important finding is that the wheel traffic confined to permanent traffic lanes made it possible to substantially increase the soil capacity of taking up water under intensive rainfall – compared to a part of the land with random passes. The soil loss by wash during water surface runoff was also lower with controlled traffic farming compared to the variant with random passes. Hence it is to assume that suitable application of the CTF system may be a contribution to soil protection from water erosion.

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