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Reduction in soil organic matter loss caused by water erosion in inter-rows of hop gardens

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Abstract: Currently, when cultivating *Humulus lupulus*, there is no systematic farming reducing soil erosion in the Czech Republic. As a result, annual irreversible soil and organic matter losses due to intensive rains occur on soils of hop gardens threatened by erosion. One of the possibilities how to reduce water erosion in hop gardens and thereby to decrease the amount of washed away organic matter is using the conservation effect of suitably selected catch crops in inter-rows. Two catch crops were selected to test: *Phacelia tanacetifolia* and a grass-legume mixture. Organic matter in soil is a key factor to maintain the stable soil environment and our results show that the amount of washed away organic matter was reduced by more than half compared to conventional farming (60% – naturally moist soil, 54.5% – soil already saturated). The research was conducted between the years 2016 and 2017 close to the village of Solopysky. Soil loss was investigated using a rainfall simulator from which the organic matter washing away was consequently determined. The rainfall simulator is a device enabling to measure not only the soil loss due to water erosion but also the volume of surface runoff, infiltration etc. From the outcomes of measurements carried out with rainfall simulator it is apparent that these technologies have a significant soil conservation potential in hop gardens.

Keywords: catch crops; permanent crops; soil conservation technologies; soil degradation

Soil water erosion is the process by which soil material (either organic or inorganic) is removed from its initial place by a combined action of raindrop energy and runoff (Goebel *et al.* 2005). It is one of the principal mechanisms of land degradation (Lal 2003; Bationo *et al.* 2007) and very serious worldwide issues. In the Czech Republic more than 51% of agricultural land is threatened by soil degradation (Šarapatka & Bednář 2015). It is vital to realize that one centimetre of soil takes decades up to hundred years to form and the consequent renewal of degraded soil is a very lengthy and expensive process and in many cases the remedy-renewal process is not even possible (Randolph 2004). If the soil is to fulfil all its functions, its fundamental properties cannot be principally affected. For more than a century, soil organic matter has been recognized as a key determinant of soil fertility and

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agricultural production (Hilgard 1906; Tiessen *et al.* 1994; Bordonal *et al.* 2017). Due to an optimum amount of good-quality organic matter in soils, the soil is able to fulfil a range of irreplaceable processes which have a significant influence on physical and chemical soil properties (Reicosky 2003) and play a critical role in sustaining soil quality and sustainable agricultural productivity (Amundson *et al.* 2015). Organic matter undergoes transformations in soil, such as mineralization, humification, assimilation or stabilisation (Guggenberger 2005). Humification has the most significant effect on soil fertility (Pettit 2004). Humus also contains substances which can affect plants as hormonal stimulators. Even a small amount of humus can significantly improve the soil ability instrumental in plant growth (Brady & Weil 2002).

Organic matter loss in soils is generally regarded as the most significant factor of soil degradation process. Numerous studies have demonstrated that soil erosion has significant negative impacts on the organic matter and nutrients in soils and sediments (Gregorich *et al.* 1998; Fu *et al.* 2009; Kirkels *et al.* 2014). The loss is caused predominantly by wind and water erosion and by insufficient supply of organic fertilisers into soils (Ritter & Eng 2012). Soil particles are taken by erosion along with the fine humified part of soils, which is the most precious part of soil profile and its lack significantly influences the scope and speed of degradation processes. These processes have strong impacts on soil organic carbon dynamics in soil (Lal 2005; Xiao *et al.* 2017)

Water erosion is particularly manifested on sloping plots of land in crops insufficiently covering the soil surface. One of the crops which significantly contribute to water erosion and consequently to organic matter loss is hop. The hop is a permanent crop remaining on one plot for 20 to 25 years, sometimes even longer (Štranc *et al.* 2012). All over the world the hop is cultivated in row spacing from 2.7 to 4.2 m and if the hop garden is located on a hillslope and the soil conservation in inter-rows is not sufficient, it is easily prone to water erosion. These hop gardens lose their most fertile part when torrential rains occur.

One solution could be using catch crops intended for green manure (Duran-Zuazo & Rodriguez-Plequezuelo 2008; Marques *et al.* 2016). Catch crops are thought to be suitable underplanted crops cultivated in inter-rows of hop gardens (Krofta *et al.* 2012). Catch crops have long been valued for their soil conservation benefits (Kaspar & Singer 2011; Chatterjee 2013) including reduction in runoff and soil erosion (Gómez *et al.* 2009; Jahanzad *et al.* 2017; Etemadi *et al.* 2018), improvement of soil structure (Palese *et al.* 2014) and increase in infiltration and soil organic carbon content (Vanderlinden *et al.* 1998; Marquez-Garcia *et al.* 2013). Catch crops can also be a promising option to accelerate carbon sequestration (Paustian *et al.* 2016; Pardo *et al.* 2017). A suitable combination of catch crops has a positive effect on soil structures also due to underground biomass. Underground biomass is understood as the root system of crops. Roots are one of the main sources of carbon and nitrogen in soils (Zdruli *et al.* 2004; Rasse *et al.* 2005); their labile carbon compounds and root exudates contribute to the stabilization of soil in the upper 5-cm layer (Jackson *et al.* 2017).

MATERIAL AND METHODS

The research was conducted near the village of Solopysky, which is located 12 km south-west of the town of Louny. Typical climate is slightly warm and dry. Mean annual rainfall is 450–550 mm and temperature 7–8.5°C. The terrain of wider surroundings is significantly rugged. Soils are luvic Cambisols due to texture differentiation. In irregular locations there are fluvic characters (IUSS Working Group 2015). The main soil-forming process is weathering permacarbon with neutral or weak alkaline reaction. The basic soil properties: 1.53% total oxidizable carbon (Cox); humus 2.64%; total nitrogen (Ntot) 0.184; C/N ratio 8.3. The topsoil layer up to 50 cm (the soil texture: < 0.002 mm – 23.8%; < 0.01 mm 36.5%; < 0.05 mm – 66.7%; < 0.1 mm – 84.4%). There are mentions of soil compaction in wheel tracks. These tracks are unfortunately an inseparable part of hop gardens due to the frequent traffic of agricultural machinery.

Plots for tested technologies were selected particularly for their height and uniform slope, which exceeded 17% in some parts. Soil conservation effectiveness of tested technologies was better manifested due to the great slope of parcels. Experimental plots had a length of 16 metres.

In total 4 technologies were selected to test and check the amount of organic matter washing away. Two technologies were selected as the control ones (Wischmeier & Smith 1978) and the two remaining technologies were soil conservation technologies

https://doi.org/10.17221/135/2018-SWR

with catch crops. In 2016 the experimental plots with catch crops were established always twice. For this reason, it was possible to carry out two rain simulations for each type of catch crop during one term. A more detailed description of tested technologies can be found in the following text:

(a) bare soil (control plot) – experimental plot is completely without plant cover,

(b) conventional farming (control plot) – the classical way of hop farming,

(c) conventional farming with sowing of *Phacelia tanacetifolia* – no-tillage sowing of *Phacelia tanacetifolia* in the amount of 10 kg/ha was carried out,

(d) chisel ploughing with the sowing of grass-legume mixture – no-tillage sowing of grass-legume mixture was carried out (*Pisum sativum* 20%, *Vicia sativa* 20%, *Avena sativa* 30%, *Triticum aestivum* 30%) in the amount of 120 kg/ha.

Rainfall simulator was used to measure soil erosion and consequent organic matter loss. It is a device which is used to a larger extent to study soil erosion processes, and the use of rainfall simulators is widely accepted (Chmelová & Šarapatka 2002; Iserloh *et al.* 2013; Martínez-Murillo *et al.* 2013; Lassu *et al.* 2015). The principle of measuring with rainfall simulator is based on rainfall simulation on a clearly defined and designated area. The size of the rainfall simulation area is 21 m^2, from which subsequently surface water along with eroded soil particles runs off. The rainfall simulator allows for monitoring not only the erosion effect, but also the rainfall and infiltration capacity of soil or the beginning and the end of surface runoff. Therefore, results and outcomes from a rainfall simulator offer a comprehensive set of information about selected technologies and their soil conservation effectiveness in the course of torrential rainfalls. When testing, it is necessary to ensure that soil and slope conditions of individual options are as similar as possible. For this reason the technologies were established and tested on the same plot.

Rainfall simulation on the designated area was done twice consecutively. The duration of the first rainfall simulation was 30 min, after which a technological 15-min break followed. After the allocated time elapsed, the second (repeated) rainfall simulation with duration of 15 min was performed. Two rounds of rainfall simulation were selected in order to simulate rainfalls on the soil with natural moisture and subsequently on the already saturated soil. Tests and checks of selected technologies were done in three developmental stages of the catch crop cover on growing dates defined in the guidelines Erosion Control in the Czech Republic – Handbook (Janeček *et al.* 2012). The description of individual growth dates is below:

(*I*) – date of measurement (second growth period) – period from plot preparation to sowing up to one month after sowing or planting

(*II*) – date of measurement (third growth period) – period to the end of second month from spring or summer sowing

(*III*) – date of measurement (fourth growth period) – from the end of the third period up to harvest

As for the rainfall simulator, the rainfall intensity is set to be 60 mm/h. Conditions described by Janeček *et al.* (2012) were taken into account when constructing the rainfall simulation regime. This intensity was chosen based on the recommendation of the Czech Hydrometeorological Institute and it reflects the average intensity of torrential rainfalls in the Czech Republic.

In order to determine the amount of organic matter washed away, it is necessary to know the total soil loss during simulation and the amount of organic matter in the eroded material. Firstly, the final soil loss for individually tested technologies has to be determined. Samples of surface runoff were always taken from the water-collecting flume at the place of outflow during the measurement using a rainfall simulator. Samples were taken every three minutes with the aim to find out the total amount of eroded undissolved particles. A calibrated container of 319 ml in volume was used with the sample taken to ensure the same volume of the taken sample every time. When the simulation finished, each sample was dried in a Memmert UFB 400 oven (Memmert, Germany) for 12 h at a temperature of 105°C in laboratory conditions. After drying, the weight of undissolved particles (mg) in each sample with the volume of 319 ml was determined. The number of samples varied in individual technologies depending on the beginning of surface runoff. The average amount of washed undissolved particles for the particular technology was determined from the samples treated in this way.

Due to the fact that the rainfall simulator detects the course and volume of surface runoff, it is possible to determine how much water ran off from the rainfall simulation area during the particular time. Total amount of eroded sediment from the checked area can be calculated by multiplying the average

https://doi.org/10.17221/135/2018-SWR

amount of undissolved particles in one sample by the volume of surface runoff.

Consequently, dried sediment from all samples for the particular technology was put together and the percentage amount of organic matter in the taken sediment was determined using the right method. In the laboratories of Research Institute of Soil and Water Conservation, the method ISO 14235 (1998), ÖNORM L 1081, was selected as the method determining the total amount of organic matter. If the percentage of organic carbon in the total amount of eroded undissolved particles is known, then the amount of washed organic matter during simulation can be determined as well.

RESULTS

The amount of washed away organic matter is related to bare soil, which is regarded as control technology along with conventional farming. Although the same method was observed during simulation, it is not possible to compare results for individual dates and years without converting them to percentage. This is so because the soil can have different moisture and temperature parameters when testing technologies. For this reason, the final values are expressed in percentage, when bare soil is considered the basis. In this way, the possibility to compare individual dates within one year and also across years is ensured. The average amount of undissolved particles converted to mg/l from all tested technologies is shown in Table 1.

For the first rainfall simulation the second growth period was chosen. Catch crops of the grass-legume mixture reached the height of 12–13 cm. The plants of *Phacelia tanacetifolia* were 5–6 cm high at the time of rainfall simulation. The problem seemed to be the effect on experimental plot caused by wheel tracks from agricultural machinery. Surface runoff occurred just in the wheel tracks.

The second date chosen for simulation corresponded to the third growth period. During the second measurement, the vegetation cover of catch crops was fully grown in both soil conservation technologies. The grass-legume mixture reached the height of 60 cm, whereas *Phacelia tanacetifolia* only 30 cm. The wheel tracks were the problem on both experimental plots again. However, plants started lodging due to rainfall simulation, among others also in the direction of the wheel tracks, thus better soil protection from direct fall of raindrops. The best protection of wheel tracks was manifested in cover crops of the grass-legume mixture which was more resistant to the traffic of agricultural machinery.

The third testing of chosen technologies was done in the fourth growth period. In the soil conservation technology with grass-legume mixture some crops were wilted (*Vicia sativa*, *Avena sativa*) but others (*Pisum sativum*, *Triticum aestivum*) still vegetated and reached the height of about 60 cm. A similar situation occurred also with the conventional farming of *Phacelia tanacetifolia*. In this period and individual plants started to wither. The height of *Phacelia tanacetifolia* was approx. 20 cm. The basic values from measuring with a rainfall simulator are shown in Table 2.

Rainfall simulation on soils with natural moisture – measured values during rain simulations on naturally moist soils are shown in Figure 1. A polynomial curve of 3rd degree (cubic polynomial) was chosen

Table 1. Rainfall simulation – average amount of undissolved soil particles in samples taken in tested technologies

Type of technology		Undissolved soil particles (mg/l per one sample)								
		I. term			II. term			III. term		
		2016 (a)	2016 (b)	2017	2016 (a)	2016 (b)	2017	2016 (a)	2016 (b)	2017
Bare soil	30 min	162 117	NA	168 860	51 049	NA	115 676	99 555	NA	107 738
	15 min	119 625	NA	81 663	73 096	NA	74 860	66 900	NA	54 419
Conventional farming	30 min	142 953	NA	137 410	55 450	NA	136 598	102 967	NA	131 134
	15 min	96 897	NA	63 764	50 097	NA	81 486	75 183	NA	64 939
C.f + *Phacelia tanacetifolia*	30 min	98 237	96 897	72 432	10 992	16 556	67 848	16 618	38 687	7 426
	15 min	88 461	95 531	39 034	8 444	12 986	36 359	9 653	37 909	4 107
C.p. + grass-legume mixture	30 min	142 412	156 962	104 212	5 913	14 363	28 985	33 689	54 356	20 246
	15 min	113 143	100 266	67 575	5 739	13 295	13 485	24 659	25 035	9 733

C.f. – conventional farming; C.p. – chisel ploughing; NA – not available – there was only one measurement for technologies of bare soil and conventional farming in 2016

https://doi.org/10.17221/135/2018-SWR

as a connecting line of the trend between the dates of rainfall simulation. As early as on the first date, a positive effect concerning the conservation of organic matter against washing away caused by water erosion was observed in soil conservation technologies. The washed amount of organic matter was similar in both treatments with catch crops and it ranged from 16% to 37% compared to bare soil. A significant influence of soil conservation technologies on reducing the organic matter loss was clearly apparent on the second date of simulation. With catch crops, the washing away of organic matter due to water erosion was reduced nearly by 75% (in 2017 nearly by 94% in the grass-legume mixture) in comparison with bare soil. During the third rain simulation, the tested soil conservation technologies retained strong conservation efficiency in relation to organic matter loss. This efficiency was around 75% in comparison with bare soil. Results of conventional farming point out to the insufficient protection of hop garden inter-rows against organic matter washing away. The extent of organic matter washing away was usually significantly higher than the values obtained when using catch crops.

Rainfall simulation on already saturated soils – the washed away amount of organic matter during rain simulations on already saturated soils is depicted in Figure 2. The cubic polynomial was used again for the curve of development concerning technology conservation efficiency between the dates of rainfall simulations. The highest organic matter loss on the first date of rainfall simulation occurred on plots with control treatments (2016 – conventional farming, 2017 – bare soil). Differences in the total

Table 2. Measured values during the rainfall simulation

Type of verified technology			No. of samples			Surface runoff (l)			Organic matter in sediment (%)		
			2016 (a)	2016 (b)	2017	2016 (a)	2016 (b)	2017	2016 (a)	2016 (b)	2017
I. term	Bare soil	30 min	10	NA	9	360	NA	490	1.16	NA	1.24
		15 min	6	NA	6	225	NA	206	1.09	NA	1.25
	Conventional farming	30 min	9	NA	10	290	NA	323	1.18	NA	1.11
		15 min	6	NA	6	263	NA	228	1.17	NA	1.12
	C.f. + *Phacelia tanacetifolia*	30 min	7	5	9	209	102	242	1.17	1.26	1.32
		15 min	6	6	6	212	174	240	1.31	1.30	1.51
	C.p. + grass-legume mixture	30 min	8	8	9	130	137	145	1.33	0.90	1.13
		15 min	6	6	6	212	219	167	1	0.88	1.19
II. term	Bare soil	30 min	10	NA	10	286	NA	420	1.20	NA	1.11
		15 min	6	NA	5	225	NA	249	1.07	NA	1
	Conventional farming	30 min	10	NA	9	280	NA	304	0.96	NA	0.89
		15 min	6	NA	5	205	NA	202	0.97	NA	0.90
	C.f. + *Phacelia tanacetifolia*	30 min	10	10	9	261	254	142	1.67	1.42	1.28
		15 min	6	6	6	149	171	107	1.86	1.22	1.28
	C.p. + grass-legume mixture	30 min	10	10	9	261	251	74	2.11	1.35	1.48
		15 min	6	6	5	152	155	58	1.82	1.21	1.66
III. term	Bare soil	30 min	10	NA	11	385	NA	503	1.19	NA	1.42
		15 min	6	NA	6	265	NA	272	0.87	NA	1.12
	Conventional farming	30 min	10	NA	11	352	NA	294	1.01	NA	1.21
		15 min	6	NA	6	271	NA	157	0.96	NA	1.35
	C.f. + *Phacelia tanacetifolia*	30 min	11	11	11	419	423	353	1.21	1.15	1.92
		15 min	6	6	6	232	152	232	1.53	1.12	1.94
	C.p. + grass-legume mixture	30 min	11	10	11	422	323	279	1.04	1.09	1.58
		15 min	6	6	6	238	240	168	1.08	1.05	1.66

C.f. – conventional farming; C.p. – chisel ploughing; NA – not available – there was only one measurement for technologies of bare soil and conventional farming in 2016

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amount of washed away organic matter decreased in all tested technologies compared to rainfall simulation on naturally moist soils. The main reason is soil saturation from the previous rainfall simulation and low growth of catch crops. Even still, the soil conservation technologies showed lower values than bare soil and conventional farming. Both treatments with catch crops were already fully engaged when rainfall simulation on saturated soils was performed on the second date. This was demonstrated also in high soil conservation resistance to organic matter loss. Organic matter washing away in the case of using catch crops was lower by approx. 85% compared to bare soil. On the third date, soil conservation technologies showed high conservation efficiency. Both treatments with catch crops reached similar results during measuring. Washing away in inter-rows with catch crops was lower on average by 29% compared to bare soil. Technologies of conventional farming had again weak soil conservation effects on all dates of measurement. On the third date in 2016, organic matter washing away was even higher by 26% compared to bare soil.

Evaluation of the two-year research – based on the two-year research, bare soil is considered the worst treatment; it was chosen as the control plot and results of other technologies were related to it. Results of conventional farming are not significantly different compared to bare soil. This fact points out to the insufficient soil conservation efficiency of traditional farming. During the second rainfall simulation on already saturated soil, conventional

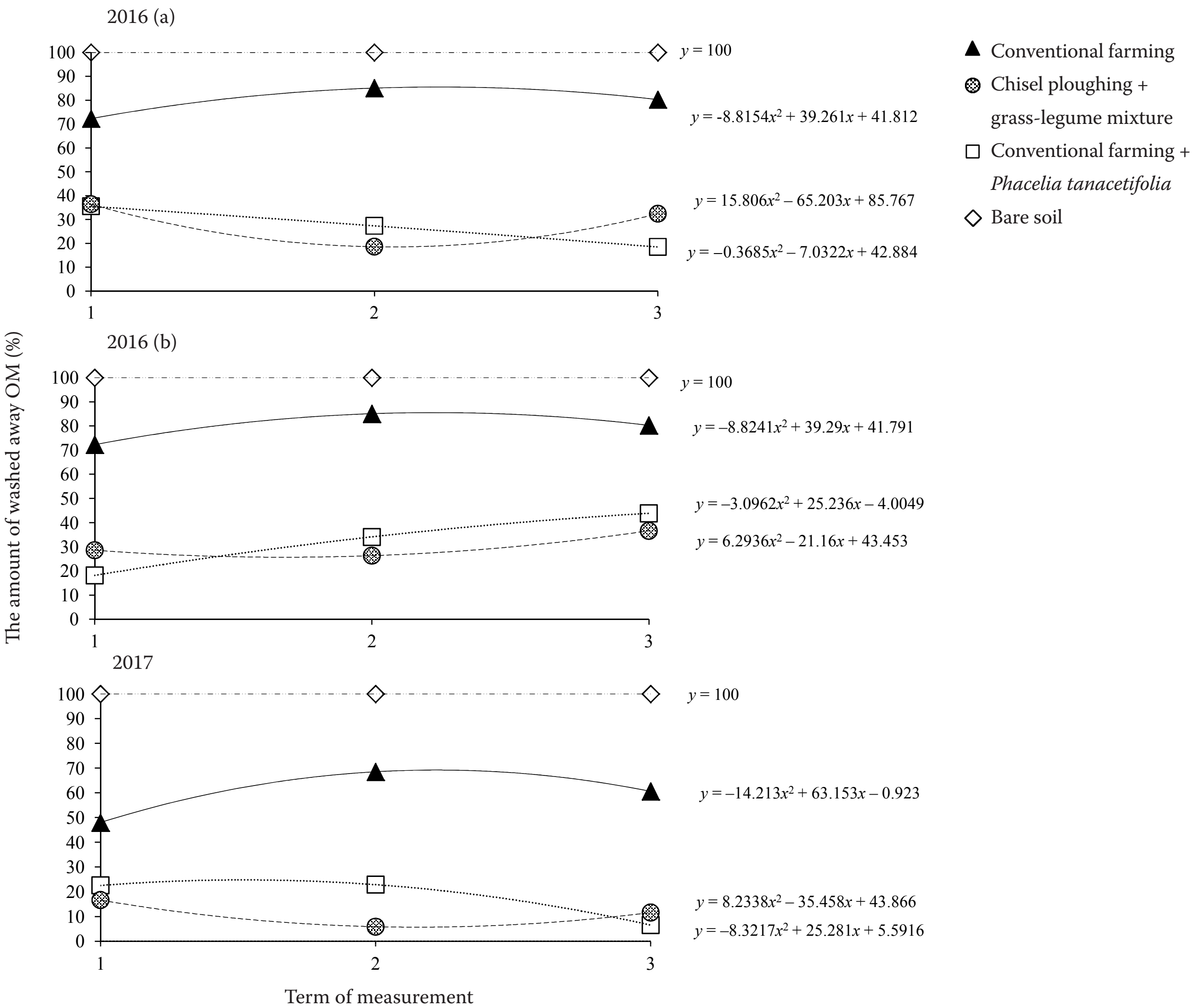

Figure 1. The amount of organic matter (OM) washed away during rain simulations on naturally moist soil (first simulation – 30 min)

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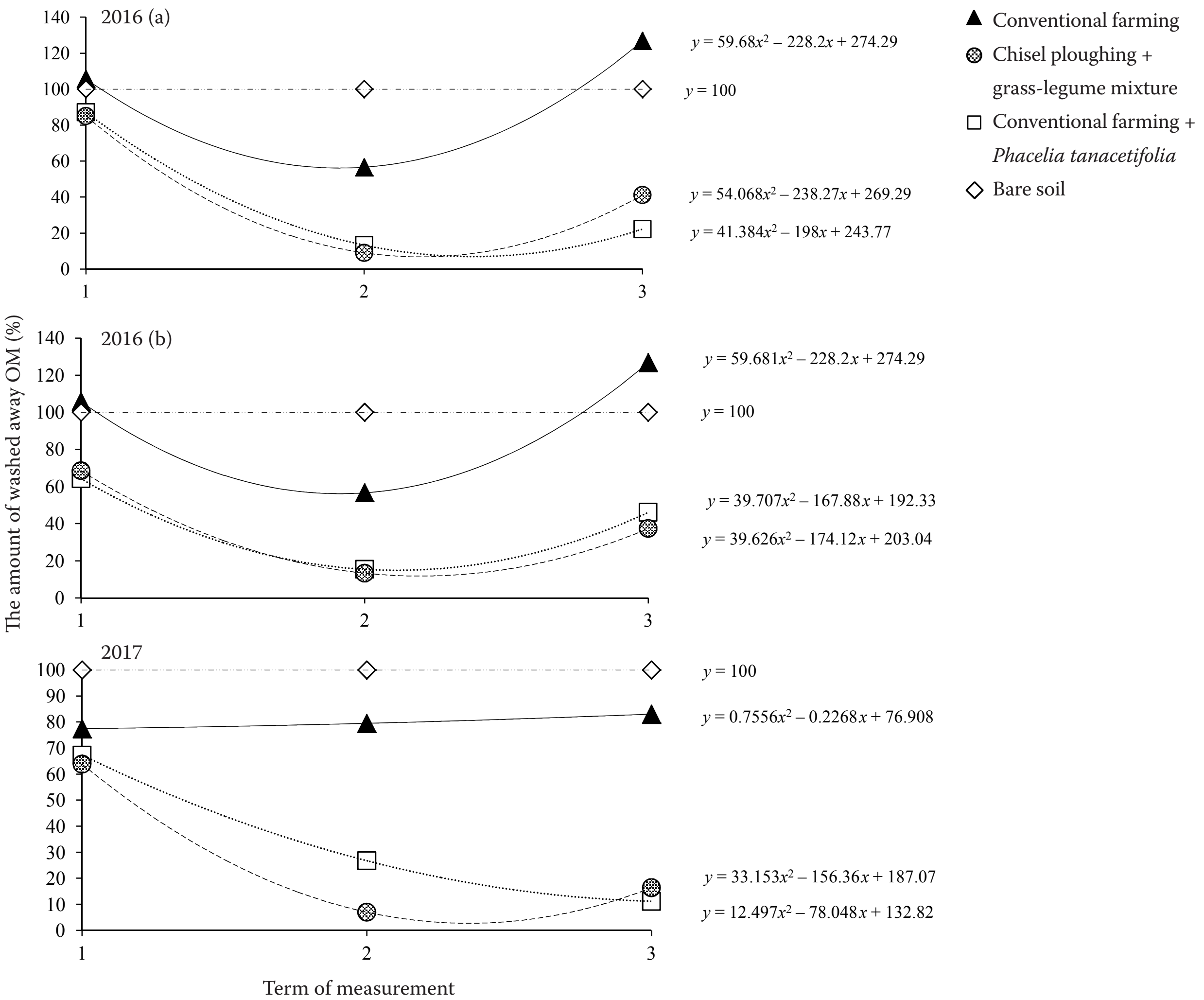

Figure 2. The amount of organic matter (OM) washed away during rain simulations on already saturated soil (second simulation – 15 min)

farming was worse in two cases compared to bare soil. Compared to the treatments with catch crops, this is a technology whose soil conservation efficiency is very low. The average amount of washed away organic matter from the two-year research is depicted in Figure 3 including an error line segment describing the deviation between the measurements.

It follows from acquired data that by using catch crops it is possible to reduce the organic matter loss from soil in the course of the entire season by more than half compared to conventional farming; both in the case of rain on naturally moist soils (66.2%), and also in the case of repeated rain on already saturated soils (59%). In all measured cases the amount of washed away organic matter was lower compared to control plots (bare soil, conventional farming). Catch crops fulfil their soil conservation function even shortly after sowing. Their efficiency increases in the course of the season up to full growth. The technologies with catch crops still maintain a high degree of soil conservation efficiency even after the end of vegetation season. One of the most important indicators of this research is depicted in Figure 4. There exists conservation efficiency of catch crops on individual dates of measurements in relation to conventional farming. The conservation effect concerning organic matter washing away due to water erosion was generally very high in the treatments with catch crops. An exception is the first date with rainfall simulation on already saturated soil. On this date the plants of catch crops do not yet reach necessary height and the soil conservation effect is not so significant as in the following measurements due to soil saturation from the previous rainfall simulation.

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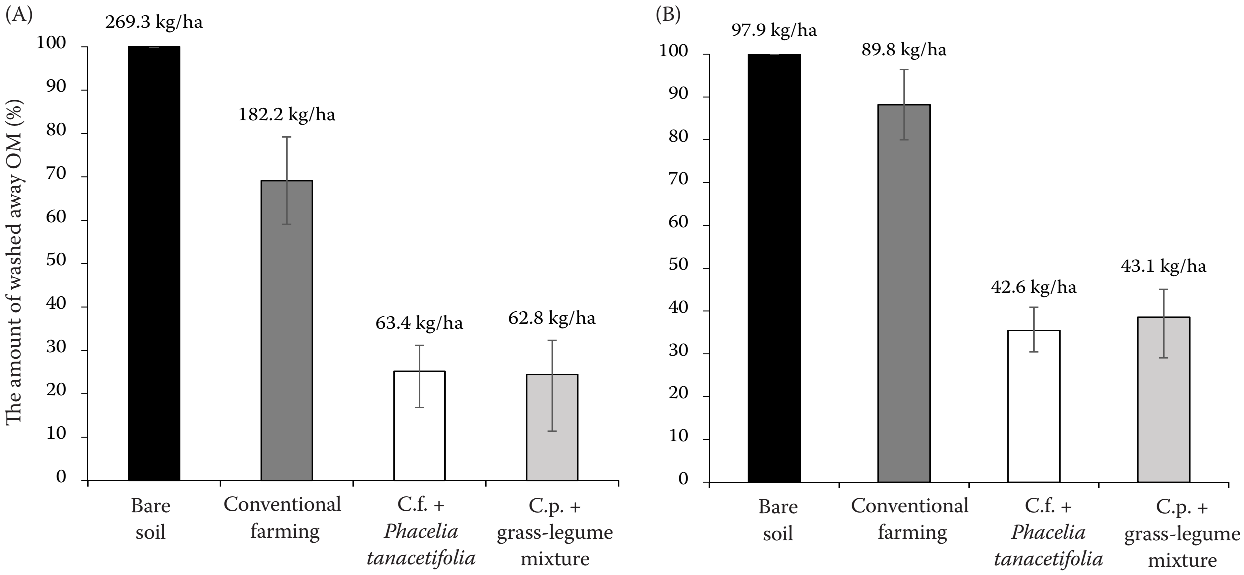

Figure 3. Average amount of washed away organic matter (OM) during simulations in 2016 (a, b) and 2017: naturally moist soil – 30 min simulation (A) and saturated soil – 15 min simulation (B)
C.f. – conventional farming; C.p. – chisel ploughing

DISCUSSION

A characteristic feature of soil conservation technologies during soil cultivation is leaving the residues of preceding crops or biomass of catch crops on the soil surface or only a shallow ploughing of these plant residues into the soil (Alberts & Niebling 1994). The same was claimed by Blanco and Lal (2010), who dealt with principles and management of soil conservation. The most important outcome of this research is the finding of a difference in the amount of washed away organic matter due to water erosion between conventional farming and technologies with catch crops. A direct correlation between erosion and soil management has been found by many authors. The lower the extent of erosion, the lower is the organic matter loss from soil. Some authors have found that soil conservation technologies reduce the erosion risk by up to 63% compared to conventional farming (Zhang *et al.* 2009). Novara *et al.* (2011) reported a reduction of erosion with catch crops from 40% to 76% in comparison with conventional technology. These results are in line with Marques *et al.* (2010). In a two-year study at the plot scale Ruiz-Colmenero *et al.* (2011) observed that inter-rows with a cover crop lost between 50% and 75% less soil than inter-rows without cover crops. Biddoccu *et al.* (2017) stated that the annual sediment

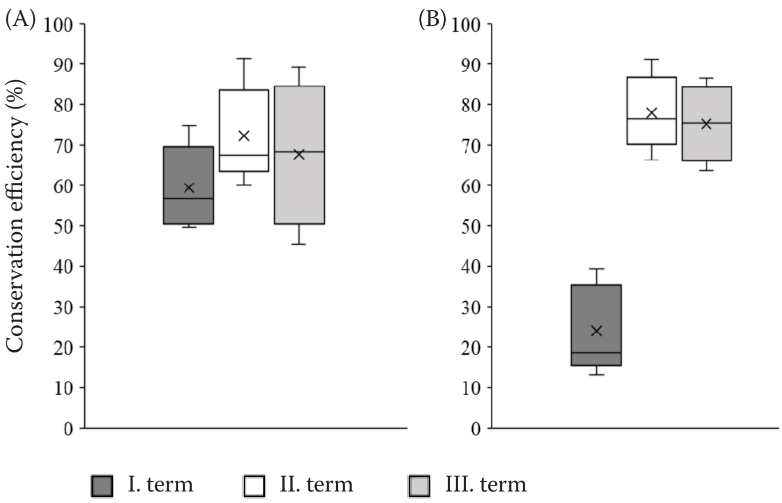

Figure 4. Conservation efficiency of catch crops compared to conventional farming: naturally moist soil – 30 min simulation (A) and saturated soil – 15 min simulation (B)

https://doi.org/10.17221/135/2018-SWR

yield in cover crops was lower by 72% to 89% than in conventional farming. Also, Morvan *et al.* (2014) measured low erosion rates for vegetation covered plots and pointed out the importance of grass cover density in the wheel tracks of agricultural machinery to prevent water runoff and erosion.

Conclusions of this study are similar. When there are catch crops in inter-rows, erosion and washed away organic matter are much lower compared to conventional farming which is without vegetation cover. The values of other authors do not differ very much from our results when the difference in organic matter washing away between soil conservation treatments and conventional farming was on average lower by 60% on naturally moist soils, and by 54.5% on soils already saturated. Some authors like Wendt and Burwell (1985) recorded a reduction of erosion higher than 90%. In this way García-Orenes *et al.* (2005) stated that catch crops, by their very presence, are able to protect the soil surface against the effect of rain drops. Moreover, catch crops reduce the amount of surface runoff and they support the formation and stability of soil aggregates. As it was mentioned by Fullen *et al.* (2006), the organic matter content in soil under 2% already significantly increases the risk of erosion. In the longer-term use of catch crops, a favourable influence on yields of main crops and on soil structure can be expected (Javůrek & Vach 2009).

CONCLUSION

The issue of organic matter loss from erosion threatened plots of hop gardens is a significant one. Because the amount of washed away organic matter was lower in soil conservation technologies in all realized measurements compared to conventional farming, it can be concluded that catch crops significantly reduce the organic matter loss in hop gardens vulnerable to erosion. On the contrary, measured values in conventional farming point out the need of using a different farming method for hop gardens if they are located on hillside plots. During the season, the amount of washed away organic matter in plots with catch crops was reduced by more than half compared to conventional farming. The soil conservation effect of technologies gradually increased in the course of the catch crop growth. The most vulnerable period is the time until the catch crop cover is at least partially closed. Nevertheless, catch crops show a significant soil conservation effect even in the first stage. Maximum soil conservation effects were found on the second date of measurement, which was done by the end of June. Thus, during the periods of the most frequent occurrence of torrential rains, catch crops prevented organic matter loss from the plot threatened by erosion.

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