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Impact of cover crops in inter-rows of hop gardens on reducing soil loss due to water erosion

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Abstract: Soil degradation caused by water erosion in sloping hop gardens is definitely a serious issue because the space in inter-rows is without plant residues for most of the year in traditional cultivation. Cover crops in inter-rows of hop gardens and their efficiency in soil conservation are assessed in this article. There is only little research available in this area, and our data bring unique information on water erosion in hop gardens. Technologies with different types of cover crops were always compared with the conventional cultivation. The research was conducted within the years 2016–2020. A field rainfall simulator was used to determine the soil conservation effectiveness of selected technologies. The simulated rainfall was performed in two stages of cover crops growth with the main aim to measure the overall soil loss. The outcomes from the measurements confirmed that cover crops in inter-rows of hop gardens protect the soil surface from falling raindrops and significantly (P-value < 0.05) reduce soil loss. It can be concluded that this technology had a soil conservation effect already one month after sowing, and it is a basis for sustainable agricultural management on sloping hop gardens.

Keywords: extreme precipitation; sloping land; *Humulus lupulus* L.; permanent crops

On sloping lands, water erosion is the main factor of soil degradation and causes irreversible changes (Gao et al. 2011). Unfortunately, the problem of soil water erosion on agricultural land has been an inseparable part of the environmental threats in the last decades (Lal 1994). It negatively influences food production, drinking water quality, ecosystem services, eutrophication, mud floods, biodiversity or carbon stock in soil (Boardman and Poesen 2006). Moreover, under climate change, the frequency of extreme rainfall is expected to increase (Groisman et al. 2005, Eekhout et al. 2018), which is likely to exacerbate the problem of water erosion. It means that more agricultural lands located in a slope will require erosion control measures (Li and Fang 2016). One of the most problematic agricultural crops from the soil erosion point of view is hop (*Humulus lupulus* L.). Hop gardens are highly prone to water erosion in the traditional way of cultivation (Kabelka et al. 2019). The plants have a well-developed root system (Brant et al. 2020), but they are planted in construction with wide rows and the inter-rows of the hop garden are not protected against water erosion (Auerswald et al. 2009). In the case of sloping land, there is strong soil loss in every heavy rain (Bagio et al. 2017). Finding some information in the scientific literature about an effective soil conservation technology for hop gardens is quite problematic; however, it is possible to look at the research of other permanent crops where the situation is better. For example, several studies (Marques et al. 2010, Palese et al. 2014, Biddoccu et al. 2017) report that cover crops (or grass cover) in the inter-rows are suitable as a soil management practice adopted to reduce surface runoff and soil erosion in vineyards or orchards. Cover crops are meant to be suitable for plant species (e.g.,

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Secale cereale L., *Phacelia tanacetifolia* Benth., *Vicia sativa* L., *Sinapis alba* L., etc.) that are cultivated in the inter-rows (Krofta et al. 2012). It supposes that the cover crops growing in inter-rows of sloping hop gardens reduce soil loss and surface runoff. However, the information on effectiveness is lacking. The main aim of this article is, therefore, to quantify the soil loss in conventional cultivation (CC) technology and in soil conservation technology (SCT) with different types of cover crops in inter-rows of hop gardens.

MATERIAL AND METHODS

The research took place in hop gardens near the Solopysky village and was conducted within the years 2016–2020. This is a typical hop-growing area in the Czech Republic with a slightly warm to dry climate. The mean annual temperature is 7–8.5 °C, and rainfall is 450–550 mm. Soils in experimental plots were determined as Luvic Cambisols. The basic properties of soils are listed in Table 1. Experimental plots had the length of at least 16 meters (two-column fields) and the slope was 17% (year 2016–2018, GPS: 50.2592208N, 13.7413078E) and 9% (year 2019–2020, GPS: 50.2553675N, 13.7355892E).

In total, 4 technologies were selected to verify and check the soil loss. CC was selected as the control technology, and the three remaining SCT variants were always established in early April. All verified technologies are mentioned in the following text:

(a) conventional cultivation (CC);
(b) *Phacelia tanacetifolia* Benth. (SCT);
(c) grass-legume mixture (SCT);
(d) *Sinapis alba* L. (SCT).

A rainfall simulator with four nozzles was used to measure water erosion. It is a widespread device in the research of soil erosion processes (Chmelová and Šarapatka 2002, Lassu et al. 2015, Kabelka et al. 2020). A total of 76 rainfall simulations were performed. The principle of measuring by rainfall simulator is based on spraying water on a clearly defined area. In our case, the size of the rainfall simulation area is 21 m^2.

Table 1. The basic properties of soils in experimental plots

Soil texture (%)				C_{ox}	N_{tot}	C/N
< 0.002	< 0.01	< 0.05	< 0.1	(%)		
23.8	36.5	66.7	84.4	1.53	0.184	8.3

C_{ox} – oxidisable carbon; N_{tot} – total nitrogen

Table 2. The average distribution of R factor into months in the Czech Republic (Janeček et al. 2012)

	IV	V	VI	VII	VIII	IX	X
Factor R (%)	1	11	22	30	26	8	2

At the bottom part of the defined area, there is a water-collecting flume through which the surface runoff flows together with the eroded soil particles. Rainfall simulator allows monitoring soil loss, the amount of precipitation, water infiltration or the beginning and the end of surface runoff. Therefore, the outcomes from the rainfall simulator offer a complex set of information on verified technologies and their soil conservation effectiveness during the simulations. It is important to ensure soil and slope conditions of individual experimental plots to be as similar as possible.

Rainfall simulations on the designated area were always done twice consecutively. The length of the first rainfall simulation was 30-min. This was followed by a 15-min technological break. After that, there was the second rainfall simulation with a duration of 15 min. Two rainfall simulations were performed in order to verify the conditions of the soil with natural moisture and subsequently the conditions of the soil already saturated. Verification of selected technologies took place in two development stages of cover crops in growing terms stated in the guidelines "Predicting rainfall erosion losses – a guide to conservation planning" (Wischmeier and Smith 1978). The description of individual growing terms is stated below:

– First-term of rainfall simulations (second growing period) – the period from plot preparation to sowing up to one month after sowing or planting.
– The second term of rainfall simulations (third growing period) – the period of the second month from spring or summer sowing.

These terms correspond to the end of April (Ist term) and the end of June (IInd term). In this period, torrential rains already occur in the Czech Republic. Their distribution within individual months is shown in Table 2.

The rainfall intensity was set to be 1 mm/min. To determine the rate of soil loss, the samples of surface runoff with eroded sediments were taken every three minutes from the water-collecting flume on the place of outflow surface runoff from the simulated area. After rainfall simulation, each sample was dried in the oven for 12 h at 105 °C in the laboratory. This

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determined the weight of eroded particles (mg) for each sample. Based on the amount of eroded particles and the amount of surface runoff, the total soil loss in individual technologies was calculated. Each term of measurement and each technology (CC, SCT) was examined for normal distribution using the Shapiro-Wilk test (P-value < 0.05). In some cases, the values did not have a normal distribution, so it was decided to demonstrate the difference between technologies using the non-parametric Mann-Whitney U-test (P-value < 0.05).

RESULTS AND DISCUSSION

Results of the five-year research show that the worst technology is CC, as supposed, which was chosen as the control technology, and the SCT results were related to it. The information on soil conservation efficiency is quite unique because a considerable part of studies devoted to hop gardens is focused on hop breeding (Patzak et al. 2010), protection against harmful organisms (Bedini et al. 2015) or qualitative parameters of hops (Almaguer et al. 2014). However, there are very few research studies evaluating the soil degradation caused by water erosion in hop gardens in case they are located on slope areas. The results of CC confirm insufficient soil conservation efficiency of traditional hop gardens cultivation. On the other hand, the importance of cover crops is apparent.

The most prone period is the time shortly after cover crops sowing (Nunes et al. 2011). Nevertheless, the results in Figure 1 show a positive soil conservation effect even in their first growing stage. The highest soil losses were mostly measured in technology with *Sinapis alba*, but the positive trend is still apparent in this technology. In this article, cover crops are evaluated regardless of the crop type.

In the first term of measurement (the month after sowing), the significant (P-value < 0.05) soil conservation efficiency of cover crops was determined in rainfall simulation on naturally moist soils. The soil loss in SCT was lower by 54.9% (Figure 2) compared to CC. The initial soil moisture varied slightly from year to year. However, the most important factor is that the rainfall simulations between verified technologies in individual terms were performed in a minimum time span (usually within a day). The aim was to ensure equivalent conditions during the simulations. After the first simulation, the soil moisture conditions in the verified technologies can be considered as unified. In the second rainfall simulations on saturated soils, the differences in the soil loss decreased in all the verified SCT technologies compared to rainfall simulations on naturally moist soils. The main reasons are soil saturation from the previous rainfall simulation and the small height of plants in the first month after sowing. This meant that the soil conservation effect was not statistically confirmed.

Cover crops' soil conservation efficiency increased during the season up to their full growth (Figure 2). The maximum soil conservation effect was measured during the second term of measurement (two months after sowing), which corresponds to the end of May

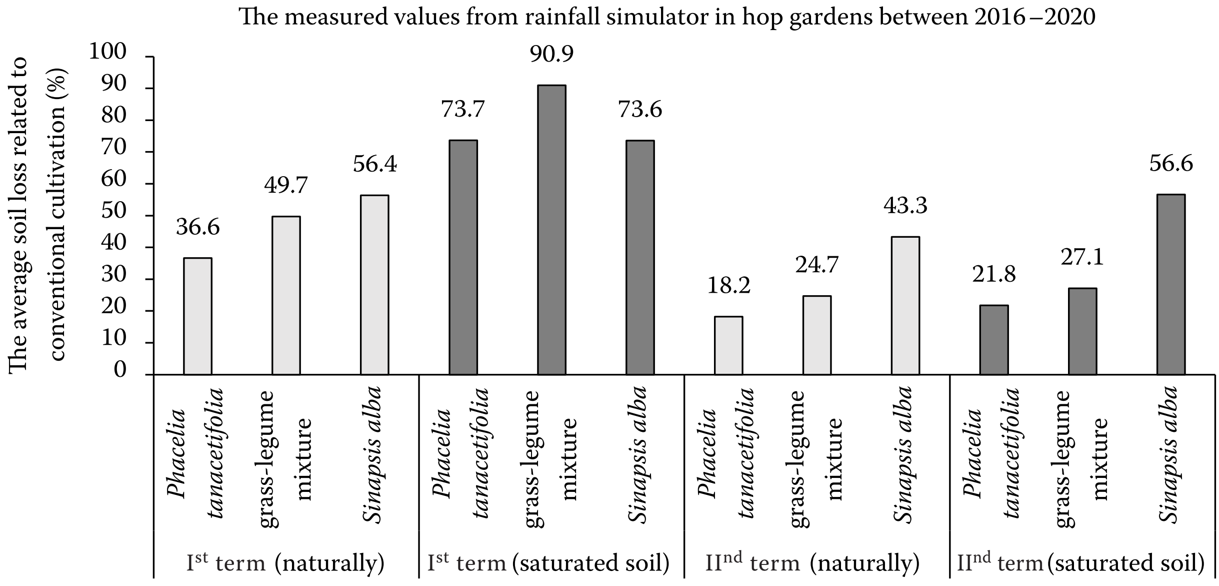

Figure 1. The average efficiency of the individual cover crops in inter-rows of hop gardens

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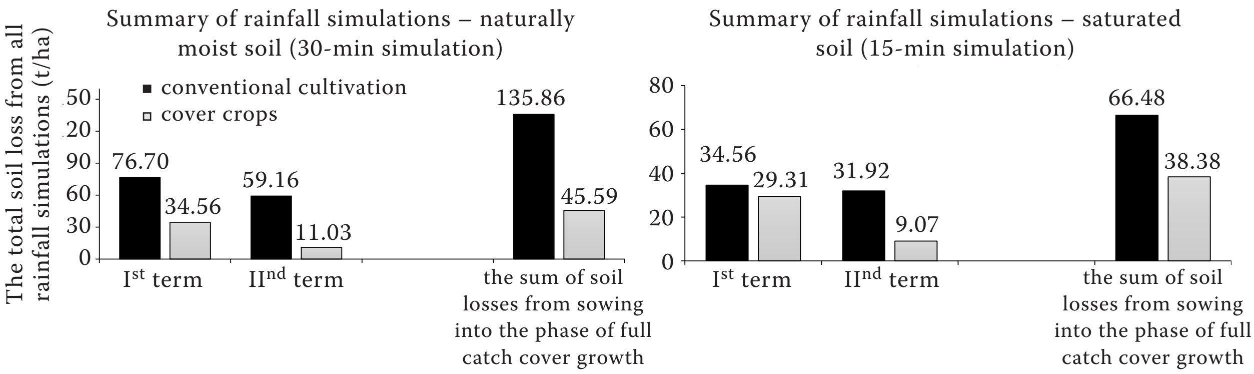

Figure 2. Overall results from all rainfall simulations in 2016–2020

when the cover crops were fully grown. A considerable influence of SCT on reducing soil loss was clearly apparent in rainfall simulations on naturally moist soils (lower soil loss by 81.4%). Due to the fact that the plants were already fully grown, a significant soil conservation effect was also measured in the rainfall simulation on saturated soils (lower soil loss by 71.6%). The outcomes from both rainfall simulations were confirmed by statistical tests (*P*-value < 0.05). The statistical indicators from our research are depicted in Table 3.

Based on our data measured in the SCT, a prediction model was determined, which shows the effectiveness of soil conservation (space between the lines) from the time of sowing for two months (Figure 3). The results indicate that if the cover crops are sown in early April, they can prevent hop gardens from the soil loss during the periods of the frequent occurrence of torrential rains. After the phase of full growth, the cover crops begin gradually dry up and generally, their leaf area index is decreasing (Reichenau et al. 2016). However, due to the fact that they are still present in inter-rows until the hops harvest, their soil conservation effect in this period is also assumed.

Of course, using cover crops is not without flaws. Track trajectories cause the biggest issues. In these places, there are traces of soil compaction, and surface runoff usually starts in these places. However, as reported by Smirnov et al. (2019), the problem of soil compaction in the track trajectories also occurs

Table 3. The statistical evaluation of soil loss from rainfall simulations 2016–2020

	Ist term		IInd term	
	CC	SCT	CC	SCT
The soil loss – naturally moist soil				
Mean (t/ha)	15.34	6.8605	11.832	2.206
Median (t/ha)	15.27	8.11	7.73	2.245
Counts	5	5	5	5
Mann-Whitney U test	hypotheses H1 group 1 > group 2			
P-value	0.048		> 0.01	
The soil loss – saturated soil				
Mean (t/ha)	6.912	5.862	6.384	1.813
Median (t/ha)	6.57	5.495	6.48	1.14
Counts	5	5	5	5
Mann-Whitney U test	hypotheses H1 group 1 > group 2			
P-value	0.345		> 0.01	

CC – conventional cultivation; SCT – technology with cover crops; CC was measured once a year for five years. Hence 5 is the number of counts; in 2016 there were 4 SCT measurements in each term, in 2017–2020 there were 2 SCT measurements in each term. The mean in both terms (Ist and IInd term) was calculated from the measured data every year. Therefore, the number of counts is also 5

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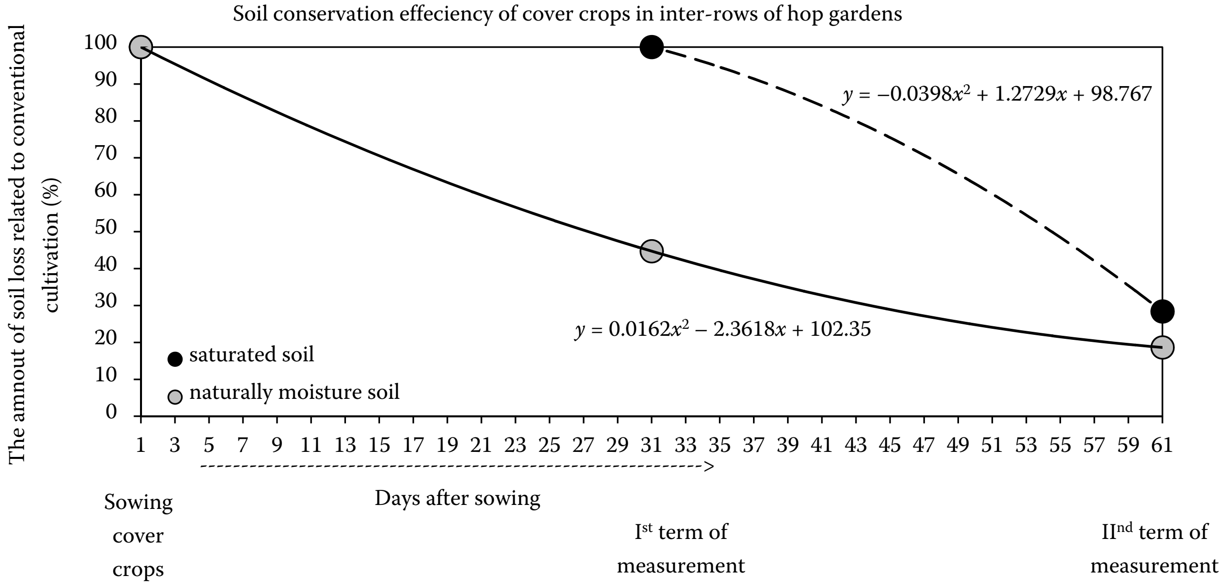

Figure 3. Prediction of soil loss in two months after sowing. The value of saturated soil in the I[st] term of measurement is 100% because the results of soil conservation technology were not statistically different from the results of conventional cultivation

in CC. It is, unfortunately, an inseparable part of hop gardens cultivating due to frequent traffic of agricultural machinery. Another problem can be weeds, which are often considered a serious threat in agriculture (Clark et al. 1998). On the other hand, some authors (Yagioka et al. 2015, Hashimi et al. 2019) state that weeds can have a similar function as cover crops. Weeds also cover the soil, so it might be possible to reduce water erosion in this way, but it is necessary to perform mulching before their reproduction in inter-rows for weeds control (Gupta 1991). Plant residues from mulching then further protect the soil from water erosion (Meyer et al. 1970).

Some comparisons of our results can be made with the research conducted in other permanent crops (vineyards, orchards), where it is possible to find out more information on water erosion. Novara et al. (2011) measured lower soil loss for SCT by up to 76% compared to CC in vineyards. In a similar way, Marques et al. (2010) state 84.6% lower soil loss in SCT. Biddocu et al. (2017) also do not differ much in the results for vineyards (lower soil loss by 72% to 89%). In orchards, Gómez et al. (2009) determined lower soil loss in SCT by 79% compared to CC. All these studies are in line with our results measured for hop gardens. Blanco and Lal (2010) state that the main cause of water erosion on sloping plots is insufficient soil cover. The conclusion of this article is the same. When the cover crops are in inter-rows, the consequences of water erosion are much lower compared to CC without vegetation. Due to the positive results in SCT, it can be concluded that cover crops in inter-rows of sloping hop gardens significantly reduce soil loss.

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