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Effects of moss restoration on surface runoff and initial soil erosion in a temperate vineyard

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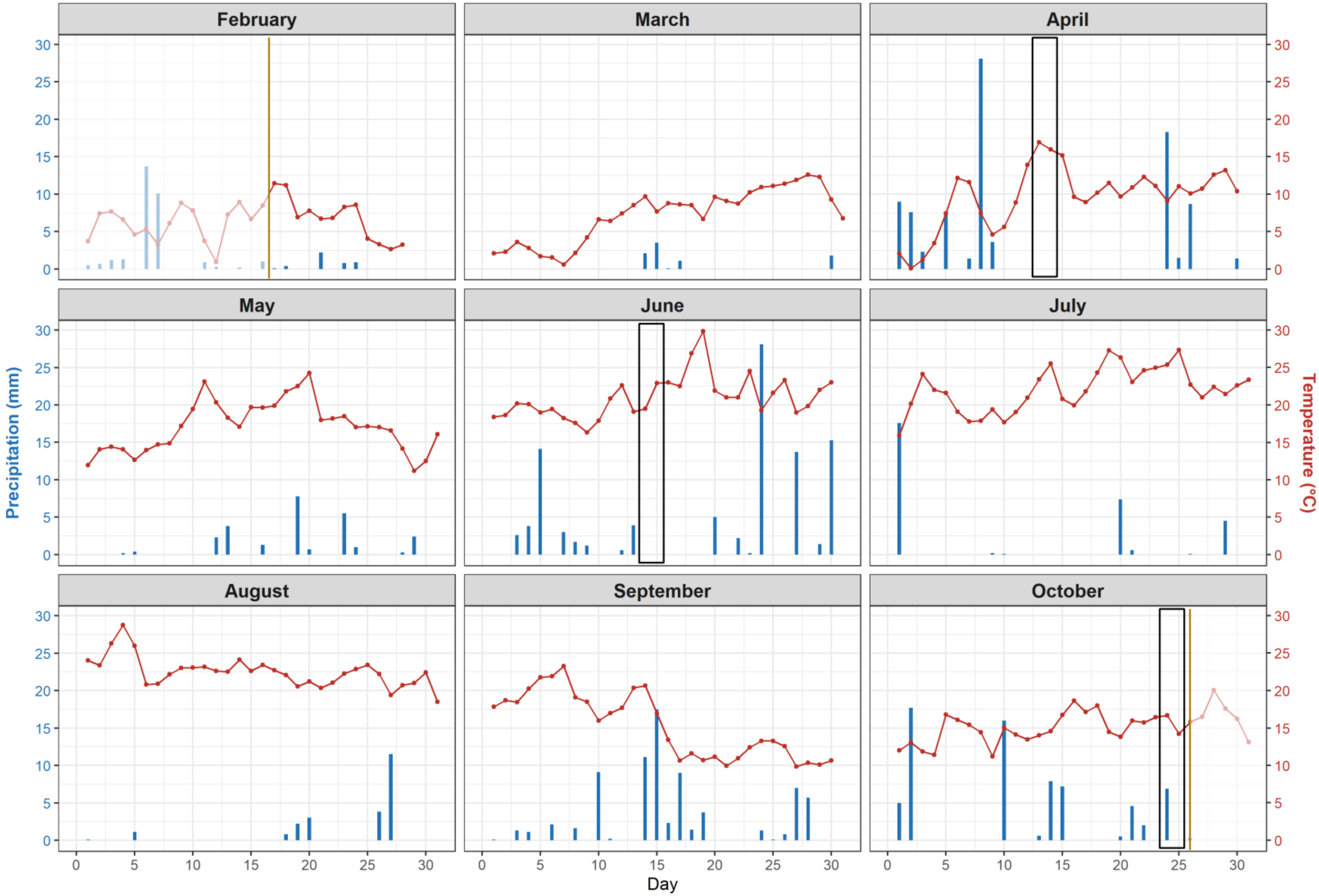
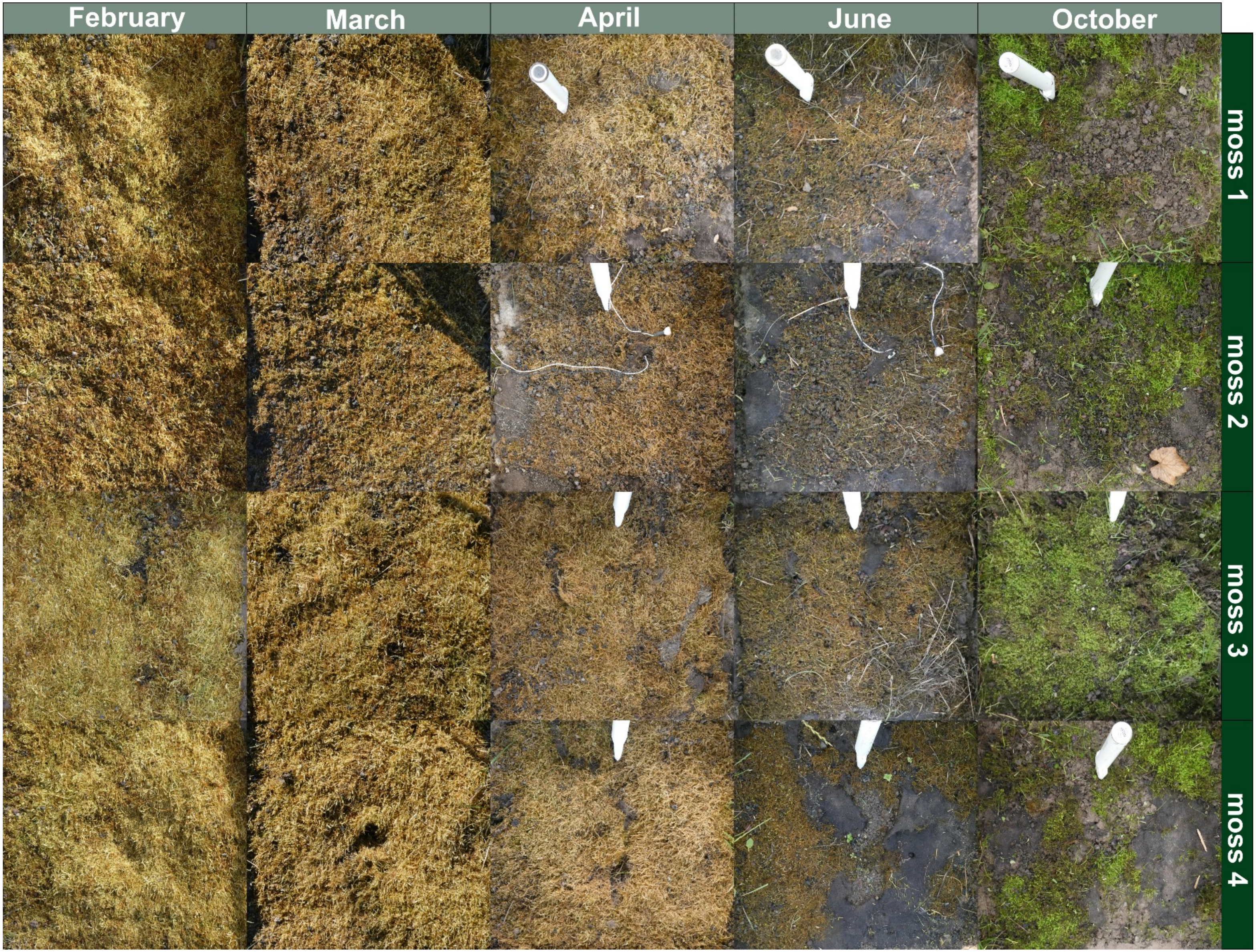


Figure S1: Weather diagrams for Fellbach with daily sum of precipitation (mm), and average air temperature (°C). The yellow lines mark the observation period from the beginning of the moss restoration on February 17, 2022, to the end of the third rainfall simulation experiment on October 25, 2022. The times of the three rainfall simulation experiments are marked with a black rectangle.



25 **Figure S2: Development of each moss restoration replicate from February to October 2022.**

Effect of moss restoration on near-surface soil water content

During rainfall simulation experiments, electrical conductivity was measured every 10 seconds in the first 5 mm of the topsoil of each treatment using biocrust wetness probes (BWP) from UP GmbH, Cottbus, Germany, connected to a GP2 Data Logger (Delta-T Devices, Cambridge, UK). Since the electrical conductivity recorded by the BWP is temperature-dependent, a correction was applied to adjust all measurements to 25 °C, following Weber et al. (2016). Furthermore, a simplified calibration procedure, as suggested by Weber et al. (2016), was used to calibrate the BWP values from electrical conductivity (mV) to a gravimetric water content ($g\ g^{-1}$). Therefore, soil samples were weighed in 100 cm^3 core cutters in both water-saturated and dry (40 °C) conditions to establish linear calibration functions for the minimum and maximum water content of each soil substrate. The 10-second time series of the water content were analysed using minute mean values, with the Wilcoxon rank sum test applied for differences between treatments and the Dunn's test for differences between measurement times within treatments.

The results of the water content measurements in the first 5 mm of the topsoil are shown in Figure S3 for all rainfall simulation experiments and treatments. Depending on the season in which the rainfall simulation experiment was carried out, differences in the course of the water content between the three treatments can be recognized.

In the first rainfall simulation experiment in April, water content in bare soil ($0.181 \pm 0.014\ g\ g^{-1}$) is significantly lower than in both grass ($0.235 \pm 0.009\ g\ g^{-1}$, $p < 0.05$) and moss treatments ($0.240 \pm 0.018\ g\ g^{-1}$, $p < 0.05$) within the first minute. There is no significant difference between grass and moss treatments. During the fifth and sixth minutes, water content remains lower in bare compared to moss treatments (both $p < 0.05$). After this period, no significant differences are observed between the three treatments for the rest of the rainfall simulation experiment.

In contrast, the second rainfall simulation experiment in June shows higher water content in bare soil ($0.238 \pm 0.009\ g\ g^{-1}$) than in moss ($0.172 \pm 0.019\ g\ g^{-1}$, $p < 0.05$) and grass treatments ($0.155 \pm 0.010\ g\ g^{-1}$, $p < 0.001$) within the first minute. Similarly, bare soil maintains higher water content compared to grass treatments in the second and third minutes. After these initial minutes, no significant differences are detected among the treatments.

The third rainfall simulation experiment in October presents a different scenario: During the first minute, water content in bare soil ($0.333 \pm 0.001\ g\ g^{-1}$) is higher than in moss ($0.309 \pm 0.001\ g\ g^{-1}$, $p < 0.001$) and grass treatments ($0.305 \pm 0.003\ g\ g^{-1}$, $p < 0.001$), with no significant difference between moss and grass. However, from the second minute onwards, significant differences are consistently observed among all treatments for the duration of the rainfall simulation experiment. Bare soil exhibits the highest water content, followed by grass, and the lowest water content is found in moss treatments.

In addition, there are notable seasonal differences in water content across the treatments. Figure S3 illustrates that water content is highest in October for all treatments, followed by April, and is lowest in June, and these visible differences are statistically significant in most cases. The only exceptions are that no significant differences are found in the bare treatment between April and June in the period of 2 to 10 minutes, in the moss treatment between April and October in the period of 4 to 9 minutes (and some individual minutes thereafter), and in the moss treatment between April and June in the period of 10 to 30 minutes.

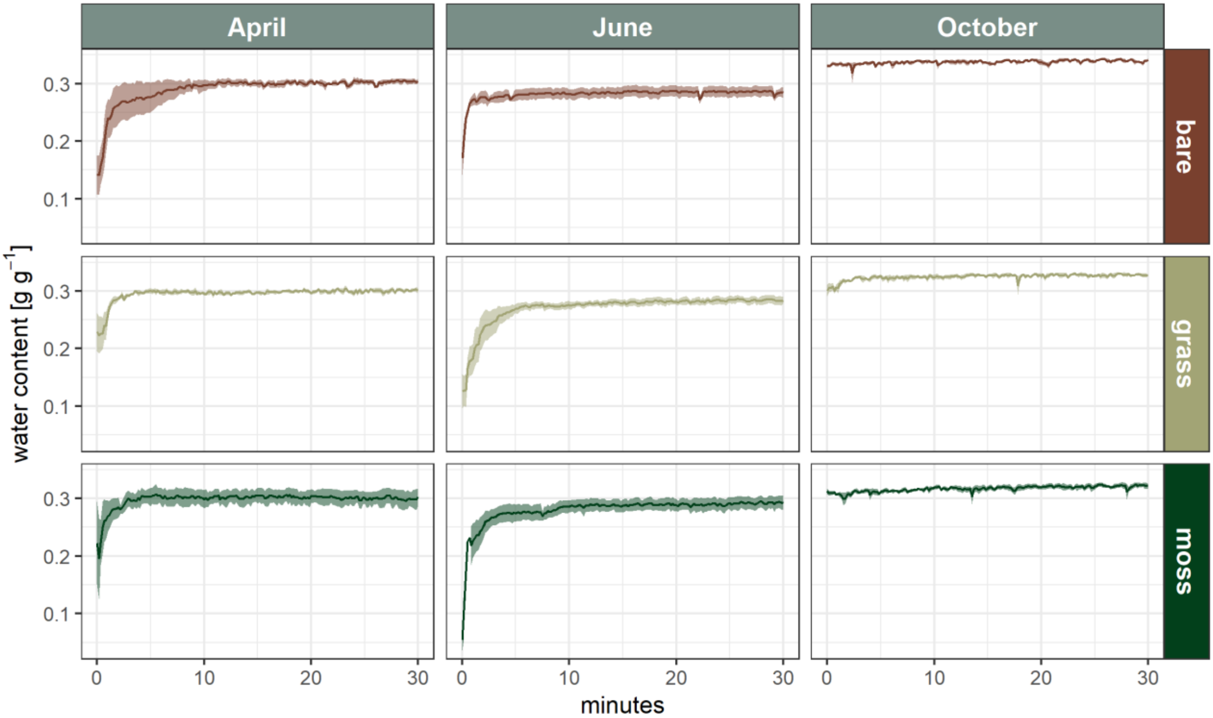


Figure S3: Temporal dynamics of soil water content [g g^{-1}] of each treatment and measurement time. The mean values of the 10-second measurements are shown as a line and the standard errors as a ribbon (*n* = *4*). Soil water content was measured with biocrust wetness probes (BWP) in the first 5 mm of the topsoil.

During the rainfall simulation experiments in April and June, there were no differences in soil water content in the upper 5 millimetres between bare soil, cover crops, and moss restoration, but the initial soil water content in bare soil was lower in April and higher in June than in both vegetation-covered soils. This can probably be explained by the weather conditions before the rainfall simulation experiments (Figure S1).

In April, there was no natural precipitation and air temperature steadily increased three days before the rainfall simulation experiment, so that the bare soil desiccated on the upper soil surface, while cover crops and moss restoration prevented desiccation of the soil surface. Similar results were obtained by Thielen et al. (2021), who found that mosses prevent the desiccation of the soil and mitigate soil evaporation. However, other studies suggest that moss-dominated biocrusts increase evaporation (Li et al., 2022a; Li et al., 2022b), although this may be due to the encrustation, which does not occur in our moss restoration. Interestingly, Chen et al. (2019) discovered that mosses actively regulate evaporation to keep their temperature below a threshold of 30°, although they are theoretically unable to do so due to their poikilohydric nature (Glime, 2021).

Despite some initial studies, the influence of mosses on soil evaporation remains enigmatic, highlighting the need for further research on this topic.

In June, there was a small natural rainfall event of less than 5 mm one day before the rainfall simulation experiment, which may have resulted in the bare soil being wetter than the two vegetation-covered soils due to rainfall interception. Interception plays a decisive role, especially in the case of small rainfall events, as water may not reach the soil (Dunkerley, 2000). As mosses can absorb a very high amount of water (Wang and Bader, 2018; Thielen et al., 2021), it can be assumed that the interception effect of mosses is also very high. For example, Price et al. (1997) found that moss covers were able to retain 16.8 mm of precipitation, corresponding to approximately 21% of the precipitation input in a boreal forest. However, the initial difference in the soil water content already disappeared after one minute of our rainfall simulation experiment, so no difference between bare soil, cover crops, and moss restoration could be found.

In contrast, there was a clear difference in soil water content between the treatments in October, with bare soil exhibiting the highest and moss restoration the lowest water contents. This indicates that the type of soil cover has a greater influence on the soil water content in October than in other seasons. Such seasonality of soil water content was also observed in a study by Marques et al. (2020), comparing cover crops with conventional tillage management in a Spanish vineyard. However, the cover crops here led to an increase in soil water content at a depth of 10 cm in autumn on wetter soils, while in spring and summer soil water content under cover crops was considerably lower compared to conventional tillage management. This is an opposite trend compared to our results, which can probably be attributed to different weather conditions and soil characteristics of the research sites.

In addition, the water content in all treatments is highest in October, followed by April and lowest in June. Such seasonal differences in soil water content were also measured by Siwach et al. (2021) at three different sites in the temperate forest zone of the Garhwal Himalayas, whereby the water content in winter was higher under moss than in the soil without moss and in the monsoon season exactly the other way round. These different responses in various seasons highlight the need to consider seasonal variations in soil and vegetation management practices.

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