Impact of mulching on soil and water conservation in semiarid catchment: Simulated rainfall in the field and in the laboratory

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Prüfung des Einflusses von Mulchen auf den Bodenwasserhaushalt mittels Niederschlagsexperimenten im Feld und im Labor

1 Introduction

Soil and water loss is a major environmental concern in agricultural lands, e.g. in rainfed cropping systems in the Brazilian semiarid or in Alentejo, Portugal (e.g. OLIVEIRA et al., 2010; CARVALHO et al., 2002). Our understanding of hydrological processes in small basins has to be based on detailed hydro-meteorological measurements both in the field (e.g. BROCCA et al., 2011; FERREIRA et al., 2011) and in the laboratory (e.g. DE LIMA et al., 2003).

Losses of soil and nutrients are a main threat for agricultural soils, reducing soil fertility, land productivity and eventually leading to the unsustainability of agricultural production systems. Several studies have been developed

Zusammenfassung

Der Einfluss des Niederschlags auf den Abfluss, die Bodenerosion und die Bodenfeuchtedynamik ist u.a. abhängig vom zeitlichen Niederschlagsverlauf, den bodenphysikalischen Eigenschaften und der Bodenbedeckung. In semiariden Gebieten mit unbewachsenen Böden während der Trockenperioden können insbesondere an unberegneten Standorten hohe Niederschlagsintensitäten Bodenerosion und Landverlust verursachen. Unter diesen Bedingungen liefert das Verständnis der Prozesse für den Hangmaßstab auch Erkenntnisse hinsichtlich des hydrologischen Systemverhaltens im Gesamtgebiet. Daher ermöglicht die Anwendung von Regensimulatoren am Plotstandort die Beurteilung von Bodenbearbeitungsmaßnahmen wie z.B. Mulchen hinsichtlich der Wirkung auf Abfluss, Bodenverlust und Bodenfeuchte. Der Beitrag beschreibt Feld- und Laborexperimente mit Mulchen zum Bodenschutz bei variablen Niederschlagsgaben und ihren Einfluss auf die Regulierung der Bodentemperatur.

Schlagworte: Feldexperimente, Regensimulation, Erosionsschutz, Bodenfeuchte.

Summary

Rainfall impact on runoff, erosion and soil moisture dynamics is affected by several factors, such as rainfall temporal patterns, soil physical properties, and soil cover characteristics. In semiarid areas, where bare soil conditions usually occur during the dry season, particularly at rainfed (non-irrigated) plots, high-intensity rainfall events might produce large soil loss rates and long-term land degradation. In such environments, understanding of relevant processes operating at the hillslope scale may provide insights into the hydrologic behaviour in a catchment. Therefore, the use of rainfall simulators at plot scales can allow performance evaluation of conservation techniques such as mulching to reduce runoff, soil losses, and soil moisture. This paper describes field and laboratory experiments using mulching as an alternative to protect soil and water under non uniform rainfall events, and also to buffer soil temperature variations. The aim of the study is to contribute towards a better understanding on how mulching impacts hydrological processes and may mitigate land degradation at semiarid regions.

Key words: Experimental plots, rainfall simulation, erosion control, soil moisture.

focusing on the effectiveness of mulching on controlling soil losses and enhancing soil moisture. Such subject has been addressed by hydrologists from the Brazilian Network for Semiarid Hydrology (REHISA) (e.g. SANTOS et al., 2008, 2010), which has contributed to the instrumentation and monitoring of experimental and representative catchments in this region since 2002.

Runoff and sediment transport are complex hydrological components, due to the interaction of several factors. Antecedent soil conditions, soil physical characteristics, soil cover, rainfall intensities and rainfall patterns play an important role in rainfall-runoff processes, and on the resulting soil losses. CASTILLO et al. (2003) have investigated the role of antecedent soil moisture on runoff response on semiarid catchments, and verified that its relative importance depended on the rainfall intensity, and also on the presence of vegetation. SANTOS et al. (2010) noted that the surface condition significantly influenced the soil water content variation, both in the dry and rainy seasons, in a semiarid watershed in Northeast Brazil.

The effect of antecedent soil water content, soil physical characteristics and rainfall regimes on soil detachment dynamics has been largely studied. RUDOLPH et al. (1997) found that for antecedent dry conditions, intermittent rainfall regime resulted in higher amount of soil loss and produced higher micro-relief changes when compared to continuous rainfall regime. Hence, different rainfall intensity patterns and duration tend to produce different runoff peaks and different soil loss rates (e.g. ZHANG et al., 1997). TRUMAN et al. (2007) noted that compared to uniform precipitation, more changes usually occur at the soil surface when variable rainfall intensity patterns are applied. RÖMKENS et al. (2001) showed that a sequence of rainfall spells of decreasing intensity caused more soil loss than a similar symmetrical sequence comprising increasing intensity.

It has been shown that mulching influences runoff-erosion processes, soil moisture and soil temperature. However, quantifying the impacts of mulching for different rainfall intensities and durations is still a challenge. LAL (1976) verified that mulching cover densities of 4–6 tons ha^{-1} improved soil physical properties in semiarid Nigeria. COOK et al. (2006) studied the effect of different type of mulches and cover densities on soil water content and soil temperature. The authors observed that under natural rainfall, wheat straw from 2 to 8 tons ha^{-1} positively regulated the temperature of topsoil and enhanced soil water content. JIN et al. (2009) analysed the effect of three uniform rainfall intensities to four cover percentages on runoff and sediment transport. Sediment loss was positively correlated to rainfall intensities, whereas lower cover produced higher erosion. SANTOS et al. (2010) observed that the use of mulch, associated with rock barriers, provided high soil water content levels and increased the rainfed bean production. JORDÁN et al. (2010) reported that long-term mulching application improved physical and chemical properties of semiarid cultivated soil in Spain. The authors observed an increase in rainfall interception, delay in runoff generation and reduction in runoff and sediment yield under straw mulching cover with different densities. Mulching cover with 5 Mg ha^{-1} $year^{-1}$ or 10–15 Mg ha^{-1} $year^{-1}$ promoted rainfall infiltration to more than 90 % or almost 100 %, respectively, resulting in minimal or no runoff. SOUZA et al. (2011) applied 9 tons ha^{-1} bean straw as mulching in an irrigated plot located at an alluvial valley of the Brazilian northeast. They found that mulching retained efficiently soil moisture and reduced its variation coefficient.

This paper aims to investigate the performance of crop straw as an alternative to control runoff and soil losses in a hillslope of an experimental semiarid watershed located at the Brazilian Northeast. Investigation included field experiments focusing the effectiveness of mulching in reducing soil loss and further detailed laboratory investigations on relevant hydrological processes under intermittent rainfall events, including soil moisture and soil temperature dynamics.

2 Material and methods

2.1 Alto Ipanema catchment

The Alto Ipanema catchment is located in the Brazilian semiarid region of Pernambuco State (Figure 1) and is part of the São Francisco River Basin, which represents 8 % of the Brazilian territory. With an area of 183 km^2, the Alto Ipanema catchment includes the representative catchment (Mimoso) with an area of 149 km^2 and the experimental catchment (Jatobá) with an area of 14 km^2, both monitored as part of the REHISA network. Both catchments consist essentially of non-perennial streams. Shallow soils are dominant, with a thickness of less than 2 m at the hillslopes. Communal rainfed agriculture is developed in these hillslopes, usually without appropriate management.

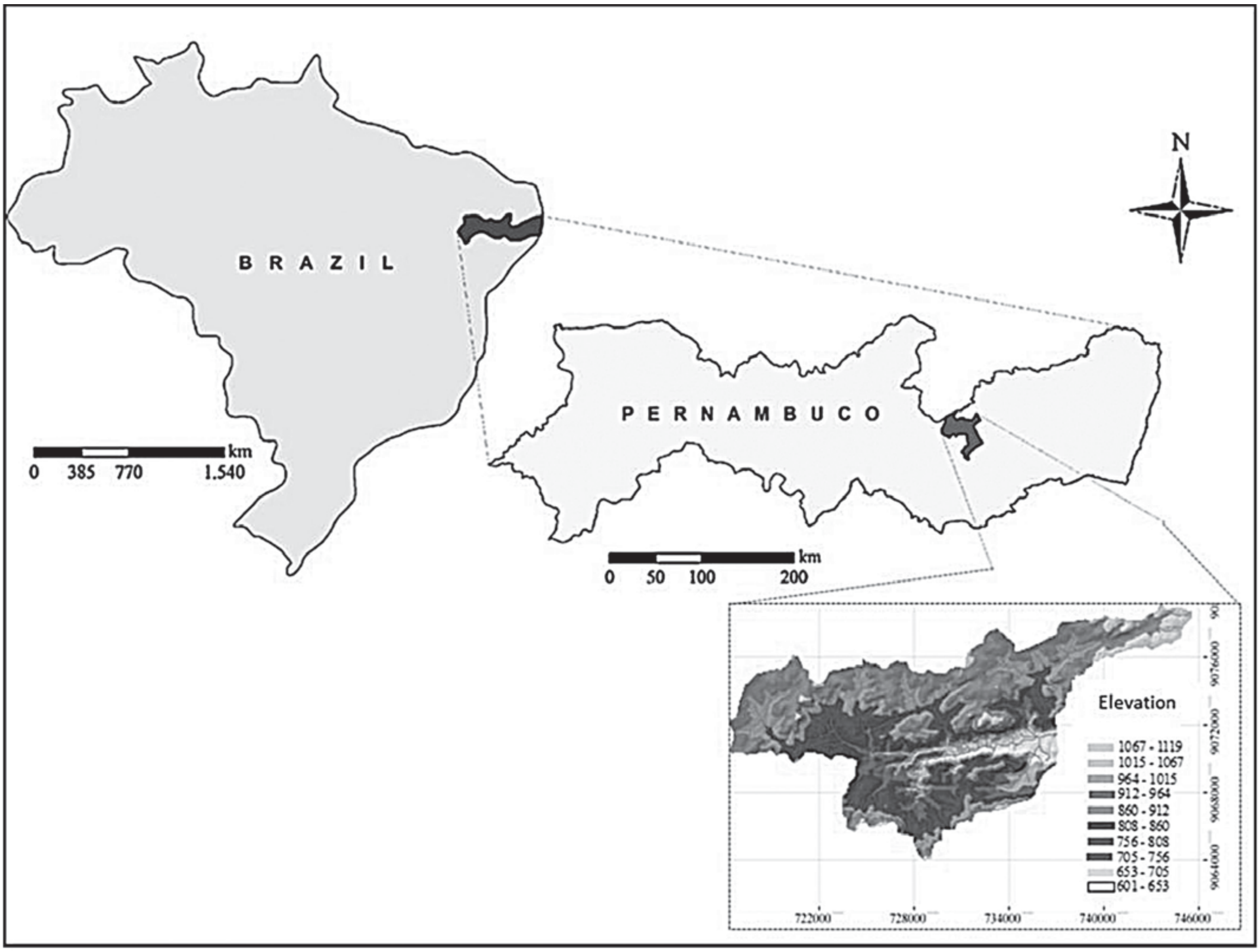

Figure 1: Location of Alto Ipanema catchment in Pernambuco, Brazil
Abbildung 1: Lage des Alto Ipanema-Einzugsgebiets in Pernambuco, Brasilien

2.2 Rainfall experiments in the field and in the laboratory

Field experiments were conducted in the representative catchment of Mimoso, on a hillslope with a 6 % slope. The soil of the area was classified as Abruptic Eutrophic Yellow Argisol, with 44.5 % of sand content, and 24.8 % of clay at 0–30 cm layer, corresponding to loam soil (SANTOS et al., 2008). Runoff and soil loss have been monitored in field experimental plots (3 m long and 1 m wide) with a rainfall simulator. An oscillating nozzle type rainfall simulator was placed at a height of 3 m above the soil surface. As described in SANTOS et al. (2008), a "Veejet 80–100" nozzle was used, operating at 30 kPa pressure, generating a rainfall intensity of 60 mm h^{-1}, which was applied for 80 minutes. Figure 2 gives an overview of the plots and rainfall simulators used in field and laboratory experiments.

Laboratory experiments were conducted using a soil flume and a rainfall simulator at Coimbra University, Portugal. The adopted rainfall simulator presented a steady single downward-oriented full-cone nozzle, from Spraying Systems Co., with an orifice diameter of 4.8 mm and at 2.00 m above the geometric centre of the soil flume surface, operating at steady pressure of 140 kPa. A detailed description of the rainfall simulator can be found e.g. in DE LIMA et al. (2003). The soil flume (3 m long and 0.3 m wide) was fixated with a 10 % slope and was filled with a sandy-loam soil from the right bank of Mondego River, in Coimbra (Portugal). The soil presents 7 % clay, 9 % silt, and 84 % sand and gravel contents.

Experiments in the laboratory comprised different rainfall events, in an intermittent way. A fixed 30-minute interval was always assumed between two successive events, allowing runoff recession to occur, as well as soil drainage. All events presented approximately the same total rainfall amount, but different rainfall intensities and durations. The first event was uniform, with intensity equal to 57±3.6 mm h^{-1}, applied during 35 minutes. The following, starting 30 minutes later, had an uniform 84±3.3 mm h^{-1} intensity, with 20 minutes duration, while the third event was also uniform with 112±3.5 mm h^{-1} rainfall rate, and lasted for only 15 minutes.

2.3 Soil covering

Mulching cover percentage was evaluated by the Mannering method (e.g. RIZZARD & FLECK, 2004; SANTOS et al., 2008), and it is defined as the ratio of the projected mulching surface per unit area. Field experiments have been carried out with 86 % covering index of bean straw. Laboratory runs have used rice straw with two mulching densities: i) low mulching cover with 75 % of covering index; and ii) high mulching cover with 90 % of covering index.

3 Results

Mulching was highly efficient on controlling detachment and soil loss, producing a reduction of the soil loss peak rate of 93 % in the field and 41 % in the laboratory. The maximum soil loss rate for the bare soil was similar for the laboratory and for the field conditions. However, mulching controlled erosion better in the field than in the laboratory (Figure 3), even considering that cover index in the laboratory was higher. This is related to the type of soil, initial

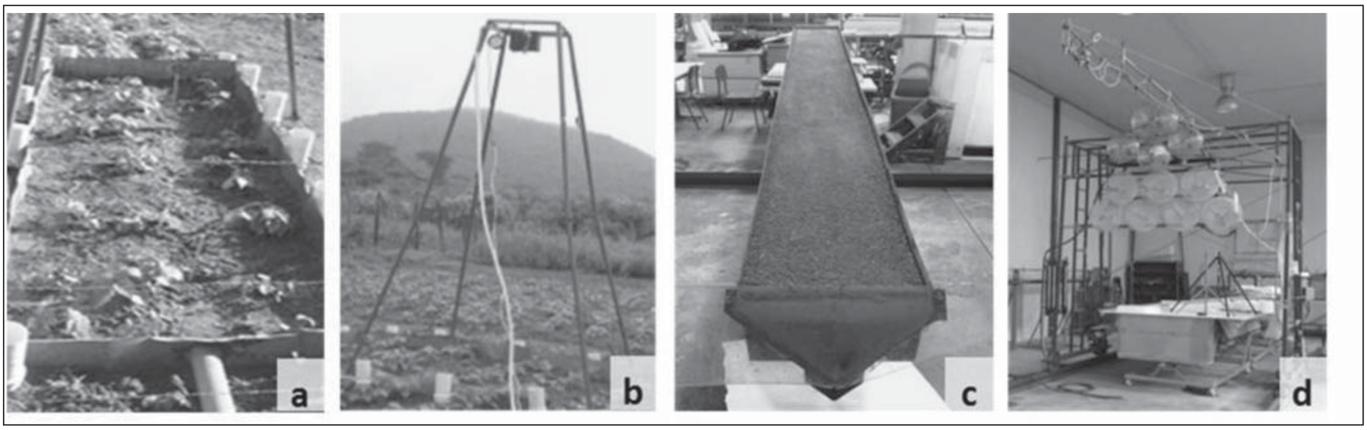

Figure 2: Field and laboratory experiments under simulated rainfall: a) Erosion plot (3 m long and 1 m wide); b) Single nozzle rainfall simulator; c) Laboratory flume (3.00 m long and 0.30 m wide); d) Laboratory rainfall simulator

Abbildung 2: Feld- und Laborexperiment mit Regensimulator: a) Erosionsplot (3 m lang, 1 m breit), b) Einzeldüsenberegner, c) Laborrinne (3 m lang, 0,30 m breit), d) Labor-Regensimulator

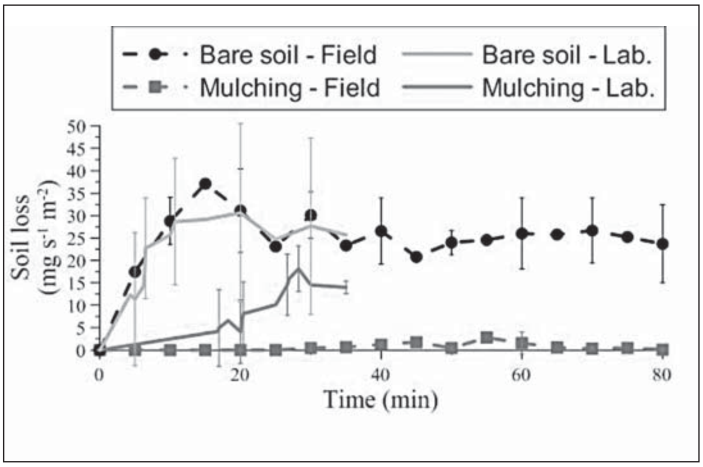

Figure 3: Soil loss rates in the field and the laboratory, under distinct soil cover conditions

Abbildung 3: Bodenverlustraten im Feld und im Labor bei bestimmter Bodenbedeckung

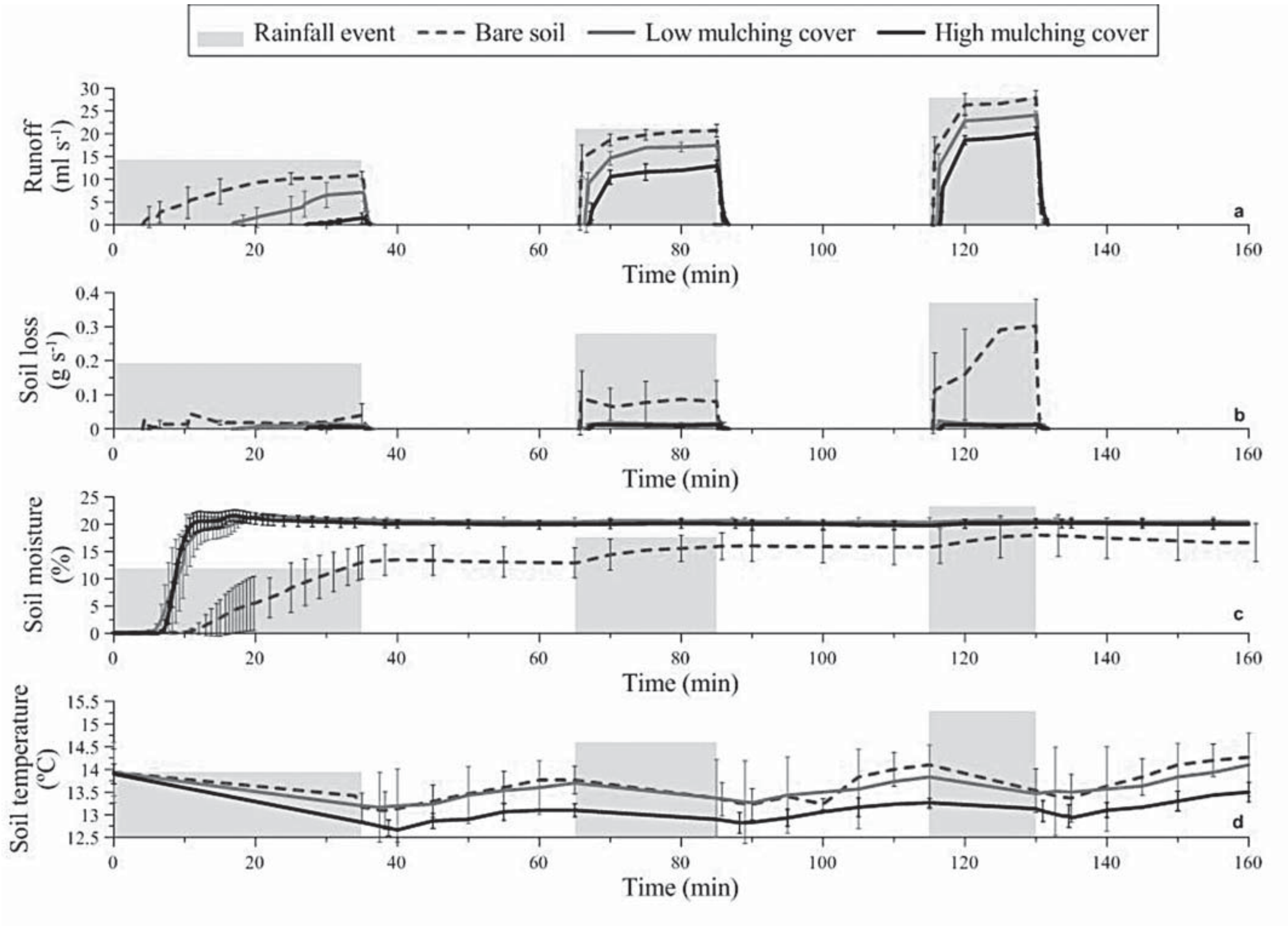

Figure 4: Results of laboratory experiments under the three successive rainfall events and for the different soil cover conditions: a) runoff; b) soil loss; c) soil moisture; and d) soil temperature

Abbildung 4: Ergebnisse des Laborexperiments bei drei aufeinanderfolgenden Regenereignissen und verschiedenen Bodenbedeckungen: a) Abfluss, b) Bodenverlust, c) Bodenfeuchte und d) Bodentemperatur

conditions, type of mulching agent and applied rainfall patterns.

Further tests were performed in the laboratory, to investigate the effect of successive rainfall events on soil loss. Runoff, soil loss, soil temperature and soil moisture dynamics in the laboratory experiments for the three successive rainfall events and for the three different soil cover conditions (bare soil, low mulching cover, and high mulching cover), are shown in Figure 4.

For all three rainfall events simulated, mulching has reduced significantly surface runoff and soil loss, although surface runoff reduction was clearer in the first rainfall event where the initial soil moisture conditions were air dry soil. Reduction of soil loss was more evident in the third event. The importance of mulching on soil moisture conservation could be observed in these laboratory experiments, but little differences occur between high and low-density mulching. In contrast, high mulching proved to be more effective than low mulching for controlling cooling and heating processes in soil.

4 Conclusions

The following conclusions can be drawn from the described field and laboratory experiments:

- Mulching using straw crops was highly effective to control soil loss both in the field and in the laboratory.

- Soil moisture was significantly and rapidly increased by mulching, and both low and high mulching cover produced similar behaviours.
- High density soil mulching cover proved to be more effective than low mulching in controlling soil temperature, although both cover densities enhanced soil temperature protection.
- Erosive intermittent rainfall events may produce high soil losses in bare soils. In such situations, mulching can be an efficient low-cost alternative for soil and water conservation in semiarid regions.

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