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Effectiveness of the application of rice straw mulching strips in reducing runoff and soil loss: Laboratory soil flume experiments under simulated rainfall

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A R T I C L E I N F O

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A B S T R A C T

The use of mulch as a management tool has shown one of the highest effectiveness/cost ratios for improving agricultural soil fertility, crop productivity, soil restoration in badlands and post-fire soil erosion mitigation. Some researchers have suggested that mulching costs can be reduced by applying it in strips rather than over the entire area. However, the implications of strip-wise mulching on the effectiveness to reduce soil erosion are poorly known. This study aimed to evaluate, in laboratory experiments, the effectiveness of strip-wise mulching with rice straw in reducing runoff and soil loss for a highly erodible sandy loam soil at a steep slope of 40%. Six mulching application schemes were compared against a bare soil. The six schemes combined two surface cover rates of 50 and 70% and three spatial patterns: mulch over the entire flume length and two strips of 1/3 and 2/3 of the flume length, both located at the bottom part of the flume. The runoff-erosion experiments involved the simulation of a sequence of three rainfall events, the latter one combining the application of concentrated flow from upslope of the soil flume. Overall, mulching was more effective in reducing soil loss than runoff (50 vs. 25%) and was significantly more effective during the first rainfall event than during the following two events (83 v. 16% for runoff and 92 vs. 53% for soil loss). During the third event, mulching effectiveness dropped significantly with increasing rates of upslope concentrated flow. Overall, mulching was more effective when applied over the entire flume length than over the 1/3 and 2/3 flume's length strips, both in terms of runoff (24 vs. 21 and 13% at 50% soil cover and 41 vs. 33 and 16% at 70% soil cover) and of soil loss (44 vs. 50 and 33% at 50% soil cover and 71 vs. 60 and 39% at 70% soil cover). Even so, these differences were not significant. Therefore, strip-wise mulching can be an effective approach to substantially reduce costs or to maximize the area that can be treated. Its main disadvantage may be that it does not avoid runoff generation and associated transport process in the slope areas where no mulch is applied.

1. Introduction

For a long time, soil and water conservation practices, such as mulching, have been used to improve agricultural soil fertility and crop productivity (Kader et al., 2017) and to promote soil restoration in degraded or vulnerable areas, such as badlands (Bochet and García-Fayos, 2004) and forest lands following wildfire (Bautista et al., 1996). Mulching can improve soil fertility and crop productivity in various manners, such as by increasing water availability through increasing infiltration and reducing evaporation (Adekalu et al., 2007; Montenegro et al., 2013a; Mupangwa et al., 2007), by reducing soil nutrient losses (Qin et al., 2015), by decreasing soil temperature fluctuations (Cook et al., 2006) and by controlling weed infestations (Yordanova and Gerasimova, 2016). In recently burnt areas, mulching has typically been found to be more effective in reducing post-fire erosion than other emergency stabilization measures, such as seeding and construction of log and shrub erosion barriers (Robichaud et al., 2000; Lal, 1976, MacDonald and Larsen, 2009). Furthermore, by reducing mobilization of wildfire ashes and associated transport of pollutants such as metals and PAHs (Campos et al., 2012, 2016) as well as nutrients (Ferreira et al., 2016a,b), mulching can also be expected to reduce the risk of contamination of downstream water bodies.

The effectiveness of mulching in reducing runoff and soil loss can be attributed to three main aspects. Firstly, mulch confers protection to the

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soil surface against the direct impact of raindrops, reducing splash erosion and soil detachment and, thereby, limiting the availability of detached soil readily transported by runoff (Gholami et al., 2013) as well as reducing soil surface crusting, sealing and compaction (Cook et al., 2006; Jordán et al., 2010; Montenegro et al., 2013a,b; Zonta et al., 2012). Secondly, mulch increases the hydraulic roughness of the soil surface, thereby reducing surface flow velocity and its transport capacity (Montenegro et al., 2013a,b; Shi et al., 2013). Thirdly, mulch entraps water and soil (Cerdà et al., 2016; Foltz and Wagenbrenner, 2010; Groen and Woods, 2008; Pannkuk and Robichaud, 2003; Prats et al., 2012, 2016b; Robichaud et al., 2013), especially in the beginning of a rainfall event when the mulch is dry and its capacity to retain water and soil particles is highest.

Existing studies have addressed the effectiveness of a wide range of mulch types. This includes a multitude of straw mulches of different species, such as elephant grass (Adekalu et al., 2007), rice (Gholami et al., 2013; Montenegro et al., 2013a,b), wheat (Jordán et al., 2010), soybean (Cook et al., 2006), maize (Mupangwa et al., 2007) and barley (Cerdà et al., 2016), and also other materials such as eucalypt chopped bark (Prats et al., 2012, 2016b), wood strands (Foltz and Wagenbrenner, 2010) and pine needles (Pannkuk and Robichaud, 2003; Hosseini et al., 2017). Surface application of polyacrylamide (Prats et al., 2014) and hydromulch (Prats et al., 2016a) were also studied. All of these studies, however, tested the effectiveness of a single mulch application rate applied in a homogeneous way over the entire area to be treated.

A possible manner to reduce the costs of mulching or, alternatively, to increase the area that can be mulched, is to apply it in a strip or strips covering only a part or parts of the slope rather than over the entire slope. Such strip-wise mulching has been compared with whole-area mulching in burnt as well as unburnt forest areas, in field experiments under natural rainfall conditions (Cawson et al., 2013) and in field experiments of applied concentrated flow from upslope (Harrison et al., 2016). Bhatt and Khera (2006) studied a variety of mulch application schemes (over a whole plot, over the lower one-third of a plot, in horizontal and vertical strips) for reducing agricultural soil loss. Martinez-Raya et al. (2006) compared the erosion reduction effectiveness of different strip schemes of cover crops in agricultural lands. Xu et al. (2017) studied, in laboratory experiments, the reduction of runoff and erosion originated by a cornstalk buffer strip. Are et al. (2011) assessed the impacts of different mulching schemes on the quality of the runoff water as well as on soil nutrient status. Prats et al. (2015, 2017), in a similar laboratory experimental set-up as in the present study, used mulch of forest logging residues to compare the effectiveness of different strip-wise application schemes in reducing runoff and soil loss, under simulated rainfall as well as concentrated flow from upslope. From the above-mentioned studies testing strip-wise mulching of Bhatt and Khera (2006), Cawson et al. (2013), Harrison et al. (2016) and Prats et al. (2015, 2017), it was found that treating the entire plot with mulch resulted in lower runoff and erosion rates than treating parts of the plot only, but that at the same time, these runoff and erosion rates did not differ substantially.

Most studies on the effectiveness of mulching to reduce runoff and erosion were carried out in the field. They involved natural rainfall conditions (Are et al., 2011; Bhatt and Khera, 2006; Cawson et al., 2013; Cook et al., 2006; Martinez-Raya et al., 2006; Mupangwa et al., 2007; Prats et al., 2012, 2014, 2016a,b; Robichaud et al., 2013) as well as simulated rainfall (Cerdà, 1997; Cerdà et al., 2016; Groen and Woods, 2008; Jordán et al., 2010; Mayor et al., 2009; Montenegro et al., 2013b; Robichaud et al., 2013) and applied concentrated flow from upslope (Robichaud et al., 2013; Harrison et al., 2016). Field studies and, in particular, those under natural rainfall conditions, are typically very time-consuming and demanding in resources, as they often require many years to obtain representative results of the targeted soil and rainfall conditions (Lal, 1994). Therefore, laboratory experiments using soil flumes have been widely used to study runoff and soil erosion processes (de Lima et al., 2003, 2013; Marzen et al., 2016; Prats et al., 2018), including to determine the impacts of mulching (Foltz and Wagenbrenner, 2010; Gholami et al., 2013; Montenegro et al., 2013a; Pannkuk and Robichaud, 2003; Prats et al., 2015, 2017; Xu et al., 2017). Arguably, the main advantage of such laboratory experiments is that they allow systematic replication of a wide range of rainfall and terrain conditions (e.g., rainfall spatial and temporal characteristics, surface slope, soil roughness, initial soil moisture content, initial soil water repellency).

As a follow-up study of Prats et al. (2017), this study had as main goal to evaluate the effectiveness of strip-wise mulching of the bottom part of a slope with rice straw in reducing runoff and soil loss under laboratory conditions of elevated erosion risk. To this end, a soil flume filled with highly erodible substrate and placed at a steep slope of 40% was subjected to a sequence of three intermittent high-intensity rainfall events, the latter event also involving the upslope application of increasing, strong to extreme concentrated flow rates.

2. Material and methods

2.1. Laboratory setup

The laboratory setup schematized in Fig. 1 was used to study the effectiveness of rice straw mulching strips in reducing runoff and soil loss. The setup comprised, besides a free drainage rectangular soil flume, a rainfall simulator and a water inflow system installed at the upper part of the soil flume. Similar setups were used in Abrantes et al. (2017), de Lima and Abrantes (2014a,b), de Lima et al. (2003),

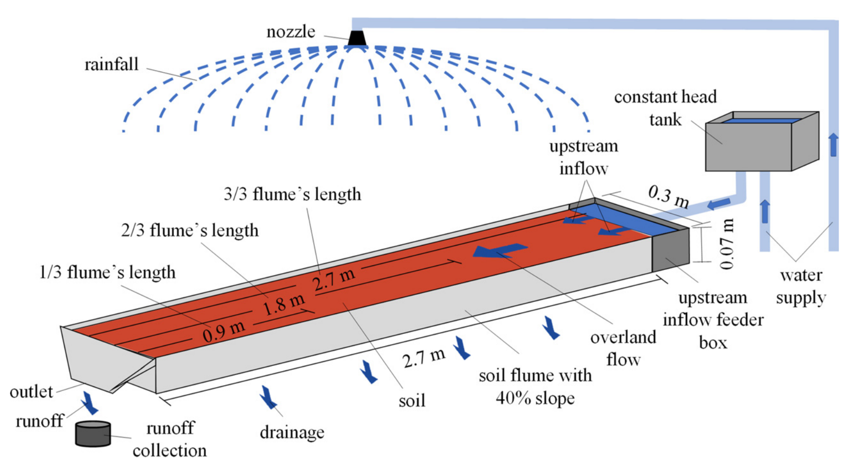

Fig. 1. Schematic representation of the laboratory setup used in the experiments (not to scale).