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Effects of subsequent rainfall events on runoff and soil erosion components from small plots treated by vinasse

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A B S T R A C T

Soil erosion control is the most essential principle for the sound utilization of soil and water. The application of soil amendments is considered as an appropriate and new strategy for soil erosion control. Despite the application of different amendments used for soil and water conservation, the durability of the effects of soil amendments during subsequent rainfalls has not been considered yet. The present study, therefore, aimed to analyze the effect of vinasse application as one of the important wastes of cane agro-industries on runoff and soil erosion components during subsequent rainfalls for a sandy clay loam soil sampled from the Alborz summer rangeland. The study was conducted under laboratory conditions using a field rainfall simulator and three small plots with a 20% slope in three replicates. The duration and intensities of rainfall were respectively designated as 15 min for 50 and 90 mm h^{-1} to one initial and four subsequent rainfalls. Experiments were then set up as a control and two treated plots with doses of 4.5 and 8 l m^{-2} of vinasse subjected to one initial and four subsequent rainfalls, respectively. The results of the study indicated that the application of the different amounts of vinasse had negative effects on the runoff commencement time, coefficient, and volume during the subsequent rainfall with an intensity of 50 mm h^{-1}. While the application of both levels of vinasse decreased soil loss and sediment concentration and had negative effects on the runoff components during the subsequent rainfall with the intensity of 90 mm h^{-1}. A high dose of vinasse decreased soil loss and sediment concentration, whereas a low dose of vinasse increased soil loss and sediment concentration. Overall, the high level of vinasse controlled hydrologic parameters better than the low level of vinasse during subsequent rainfall with different intensities. The results also revealed a significant effect of rainfall sequence on runoff commencement time, runoff volume, runoff coefficient, and soil loss ($P < 0.01$), and a non-significant effect ($P = 0.13$) on sediment concentration. On the other hand, rainfall sequence increased runoff volume and soil loss, which pointed to the need of the reapplication of vinasse soil amendment after a few rainfall events for efficient soil and water conservation.

1. Introduction

Soil erosion is one of the widespread and major environmental threats to terrestrial ecosystems, which reduces agricultural productivity and increases water pollution (Singer and Warkentin, 1996; Weltzin et al., 2003; Nearing et al., 2005). Accordingly, prevention of soil erosion is essential for natural resource management (Agassi, 1996; Lal, 1994; Morgan, 1995). Towards this attempt, application of different wastes as soil amendments is therefore one of the effective methods in order to control soil erosion as well as to manage large amounts of wastes potentially produced worldwide to fulfill human needs. Vinasse is one of the wastes produced in Iranian sugarcane agro-industries which is presently released in rivers and therefore causes dangerous impacts on ecosystem health. In fact, vinasse, as a by-product of the sugarcane industries, is a product of great potential agricultural interest and is supposed to be a useful fertilizer introduced in agriculture leading to increase in productivity and to reduction in soil erosion (Krusche et al., 2003; Gunkel et al., 2007), because of its high level of organic matter (OM) content, and N and K concentrations (Madejon et al., 2001). However, the sugarcane vinasse may cause changes in the physico-chemical properties of soils, rivers, and lakes over a long period of time, and also have adverse effects on agricultural soils and biota in general because of its low pH, high electrical conductivity, and chemical contents (Christofoletti et al., 2013).

Many literatures have reported different aspects of application of soil amendments on changing hydrologic components throughout the globe. But few studies have been reported on application of vinasse for soil and water conservation. In this respect, Madejon et al. (2001) used three (sugar-beet) vinasse composts and assessed their effects on crops and chemical properties of a cambisol soil in the Guadalquivir River valley (SW Spain). They reported that three vinasse composts increased humic acid, soil nitrogen and agricultural production. Tejada and Gonzalez (2006) applied two beet vinasse forms (fresh (BV) and composted with a cotton gin crushed compost (CV)) and found that

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CV decreased soil loss, but BV deteriorated soil properties and therefore increased soil loss. Moreover, beneficial effects of the composting of beet vinasse with vermicomposts on the soil's physical, chemical and biological properties have been reported by Tejada et al. (2009). Hazbavi and Sadeghi (2015) investigated the effect of three rates of vinasse viz. 0.5, 1 and 1.5 l m^{-2} on runoff and soil loss control using 0.25 m^2 experimental plots at 20% slope and rainfall intensity of 72 mm h^{-1} with a duration of 0.5 h. They indicated that the use of different doses of vinasse did not significantly ($P > 0.05$) reduce the runoff and soil loss except for the 1.5 l m^{-2}-treatment, which non-significantly increased the runoff volume.

It is clearly implied from the literatures on application of vinasse for soil and water conservation that vinasse, like other soil amendments, not only affected differently on hydrologic responses but also its performance was different under various conditions. However, the effect of hydrologic conditions has been rarely considered, while, studying the comparative performance of experimental treatments under different hydroclimatic conditions is a vital need to designate appropriate soil and water conservation measures. In this respect, rainfall frequency and the timespan between two rainfalls are also important as effective factors on infiltration, runoff and soil erosion. Erpul and Canga (1999) studied the effect of simulated subsequent rainfalls with an intensity of 60 mm h^{-1} on runoff and erosion from two clay loam and silty loam soils at a slope of 30%. They showed that the runoff and soil loss were more in subsequent events compared to the first rainfall. Whereas, the splash erosion in the first rainfall was more compared to those recorded in subsequent rainfalls. Similarly, Findell and Eltahir (1999) showed a positive correlation between subsequent rainfall and antecedent soil moisture. Kleinma and Sharpley (2003) also showed that the application of simulated rainfall repetitions with an intensity of 70 mm h^{-1} increased phosphorus concentrations in runoff. Moreover, Tongzhao and Jinyu (2009) investigated the relationship between rainfall intervals with drought and flooding and revealed that the rain delay was the main reason for flooding. Montenegro et al. (2013) also reported impact of mulching of rice straw (i.e., 2 and 4 t ha^{-1} density) on soil and water dynamics under a sequence of five different rainfall events in an intermittent way (45 rainfall events with 30 min dry spell interval between two consecutive rainfall events). Their results indicated that the mulching and the sequential rainfall events strongly affected infiltration, soil moisture, surface runoff and soil erosion. The effective role of time on the hydrological behavior of a different upslope, mid-slope, and downslope sections of a residual soil with a slope gradient of approximately 30° during a rainfall event was recently reported by Fan and Chang (2015) through an in-situ instrumentation program in Jiasian in Kaohsiung, Taiwan, in terms of soil moisture content. They found that the soil moisture content increased considerably during the rainfall event. So that the pattern of the variation of soil moisture content with time measured was similar at various depths at the instrumentation stations in the slope. The variations in the soil moisture content during a rainfall event at the downslope station were also low compared to the changes at the mid-slope and upslope stations. Inbar et al. (2015) showed that during the 1st rainstorm, PAM decreased infiltration rate and increased runoff in both contrasting soils affected by fire exposed to three consecutive simulated rainstorms and separated by drying periods. While, soil loss was reduced compared to the untreated controls. In the following storms, the reduction in soil loss persisted, but the effect of PAM on infiltration rate and runoff was reversed. Recently, Sadeghi et al. (2016) proved that the vinasse biochar mitigated the runoff and soil loss under simulated rainfall. Besides that, they reported that the performance of vinasse-produced biochar was influenced by remaining time before rainfall simulation.

Scrutinizing related literatures obviously verified the necessity of further studies for overcoming existing gap in relation with the role of subsequent rainfalls on hydrologic components under different conditions. The present study has been therefore formulated to study the effect of application of 4.5 and 8 l m^2 of vinasse on runoff commencement time, runoff coefficient, runoff volume, soil loss and sediment concentration during subsequent rainfalls for a sandy clay loam soil sampled from the Alborz Summer Rangeland, Iran.

Table 1
Main original soil characteristics (data are the means of 5 samples).

pH[a]	7.65
Electrical conductivity (μS cm^{-1})[a]	196
Clay (g kg^{-1})[b]	220
Silt (g kg^{-1})[b]	140
Sand (g kg^{-1})[b]	640
Bulk density (g cm^{-3})[c]	1.64
OM (g kg^{-1})[d]	24

[a] Determined in distilled water with a glass electrode (soil:H_2O ratio 1:5).
[b] Determined by the Robinson's pipette method (SSEW, 1982).
[c] Determined by using the core method (MAPA, 1986).
[d] Obtained by multiplying total soil organic carbon by 1.724. Total soil organic carbon was measured by the Walkley and Black wet dichromate oxidation method (Nelson and Somers, 1982).

2. Material and methods

2.1. Site description, experimental layout and treatments

The study was carried out in November 2013 at the Faculty of Natural Resources of Tarbiat Modares University, Noor, Iran on a sandy clay loam soil sampled from the Alborz Summer Rangeland with an original slope of 20%. Properties of the study surface soil (0–20 cm) are shown in Table 1.

The experimental layout was laid out in randomized complete block design with the entire number of six treatments in three replicates. The organic sugarcane vinasse was then applied as the main treatment under laboratory conditions. The general properties of the vinasse organic waste have also been summarized in Table 2.

Three treatments viz. non-amended control plot (C), plots amended with 4.5 l m^{-2} of vinasse (V_1) and plots amended with 8 l m^{-2} of vinasse (V_2) were then considered for the study. The study doses were considered based on available literatures and successful reports (e.g., Hawke et al., 2006). The vinasse was spread on the soil surface by a hand pump. The rain was then simulated 48 h after application of vinasse to increase the stability of vinasse layer on the soil surface and possibility of the application of treatments before the rainfall occurrence in the real conditions. The control plots were also subjected to the study rainfall under identical laboratory conditions on bare soils and just before applying the vinasse. Two rainfall intensities of 50 and 90 mm h^{-1} were simulated as dominant intensities with low and high return periods for the Kojour climatological station where original soil has been taken for the study. Finally, the entire experimental set-up including main treatments (i.e., vinasse organic wastes and control treatments), two rainfall intensities and five rainfall events with three

Table 2
Chemical characteristics of vinasse organic waste applied in the study.

pH	5
EC (μS cm^{-1})	1657
Density (g cm^{-3})	1.11
Organic matter[a] (g kg^{-1})	100
Ca[b] (mg kg^{-1})	137,025
Mg[b] (mg kg^{-1})	154.375
K[c] (mg kg^{-1})	Not detected
COD[d] (g kg^{-1})	91.4

[a] Determined by dry combustion method (MAPA, 1986).
[b] Determined by atomic absorption spectrometer after nitric and perchloric acid digestion.
[c] Determined by a atomic emission spectrometer after nitric and perchloric acid digestion.
[d] Chemical oxygen demand that is determined by closed reflux, colorometric method (APHA, 1998).