POTENTIAL EFFECTS OF VINASSE AS A SOIL AMENDMENT TO CONTROL RUNOFF AND SOIL LOSS

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Abstract

Application of organic materials are well known as environmental practices in soil restoration, preserving soil organic matter and recovering degraded soils of arid and semiarid lands. So, the present research focused on evaluating the effectiveness of vinasse, a byproduct mainly of the sugar-ethanol industry, on soil conservation under simulated rainfall. Vinasse can be recycled as a soil amendment due to its organic matter. Accordingly, the laboratory experiments were conducted by using 0.25 m^2-experimental plots at 20% slope and rainfall intensity of 72 mm h^{-1} with 0.5 h duration. The effect of three rates of vinasse at 0.5, 1, and 1.5 l m^{-2} was investigated on runoff and soil loss control. Laboratory results indicated that vinasse at different levels could nonsignificantly (P>0.05) decrease the runoff amount and soil loss rate in the study plots compared to untreated plots except 1.5 l m^{-2} which nonsignificantly increased the runoff volume. Also, the results indicated that the soil loss amount at the vinasse application rate of 1 l m^{-2} was the least. The average amounts of minimum runoff volume and soil loss were about 3985 ml and 46 g for the study plot at 1 l m^{-2} level of vinasse application.

1 Introduction

Soil erosion is an environmental concern resulting in increased sedimentation, turbidity and levels of pollutants in adjacent water bodies (Ebisemiju, 1990; Pieri et al. 2007; Girmay et al., 2009; Bhattarai et al., 2011, Bakr et al., 2012). According to the Forest, Rangeland and

Watershed Management Organization of Iran, about 150 M US dolars are annually spent on the watershed management projects implemented to prevent or to alleviate part of soil erosion related problems in the country (Sadeghi et al., 2011). It led to erosion control technologies receiving a great deal of attention to reduce soil erosion. Accordingly, soil erosion control has principal importance in soil management and conservation in developing countries like Iran (Newson, 2002; Haghjou et al., 2014). Besides that, soil management is important to crop productivity, environmental sustainability and consequently human welfare.

Covering the bare soil with an appropriate material is one of the soil management practices, which increases water infiltration and surface storage by enhancing the soil structure and porosity. The layer of residues protects the soil against erosion, inhibits weed germination, improves water retention, ameliorates physical and biological soil properties, and is a source of plant nutrients (Sheoran et al., 2010; Araujo-Junior et al., 2013; Prado et al., 2013). In addition, industrial processing of sugar cane to produce sugar and alcohol also generates residues, such as filter cake and vinasse, which have a great potential for use in agriculture as soil improvers and fertilizers (Prado et al., 2013). Meanwhile, to prevent soil loss many organic soil improvers are mainly used (Tejada et al., 2009; Rigane and Medhioub, 2011). Additionally, according to Tejada et al. (2006a, 2006b), the general increasing of biomass C in a soil can be associated to the constructive impact of organic materials on the soil physical properties. The application of animal, industrial and municipal wastes is also prevalent throughout the world as they can be an excellent source for nutrient and organic matter (Bhattarai et al., 2011). Several studies have evaluated the effects of composted organic wastes such as animal manure and sewage sludge compost on soil properties, quality and productivity, dissolved organic carbon and nitrate leaching (e.g. Adler and Sikora, 2005; Margesin et al., 2006; Bastida et al., 2007; Karami et al., 2012; Zornoza et al., 2013; Eykelbosh et al., 2015), but there are relatively few studies (e.g. Tejada and Gonzalez, 2006b; Tejada et al., 2007; Tejada and Gonzalez, 2008; Gholami et al., 2013; Cerdà et al., 2014a,b; Sadeghi et al., 2015a,b) on evaluating of the effect of organic waste and residues on runoff and soil loss control.

Application of organic amendment and mulches has already been proved as a method of improving soil physical properties leading to affect runoff and soil erosion (Albaladejo et al., 2000; Cerdà and Doerr, 2008; Cerdà et al., 2014a,b). Moreover, organic amendments are increasingly being examined for their potential use in preventing soil losses (Tejada and Gonzalez, 2008). There are a variety of organic amendments for soil management and conservation, with different performance and mechanisms. In spite of that, different organic amendments, viz. cotton gin crushed compost and poultry manure, beet vinasse, sewage sludge, organic urban solid refuse, sheep manure, cow manure, rice husk, finely chopped reeds, wheat straw, licorice (root) dregs (Agassi et al., 1998; Albaladej et al., 2000; Ojeda et al., 2003; Tejada and Gonzalez, 2006b; Tejada et al., 2007; Tejada and Gonzalez, 2008; Nicolás et al., 2012; Karami et al., 2012) have been used for soil conservation in agricultural and forestry soils, commonly.

Recently, with the advances in industrial sector, significant amount of wastes and residual can be produced which create another source of load on the environment. Also, the high cost of fertilizers and concerns about environmental protection have been great incentives to study the recycling of the large quantities of organic residues produced as byproducts of the sugar and alcohol agro-industries in agriculture (Prado et al., 2013). For instance, the production of one liter of ethanol generate on average between 10-15 liters of vinasse. Vinasse is classified as a class II residue, not inert but not dangerous. Vinasse, like other organic fertilizers has high organic matter, N and K contents (Madejón et al., 2001), which promotes nutrient recycling in ecosystems, and causes less environmental impacts during production. Sugarcane industries generate large quantities of waste generally known as vinasses, stillages or molasses spent wash during the process of ethanol production (Espanã-Gamboa et al., 2011). Vinasse is an important byproduct of ethanol and sugarcane industries, intensively applied to soils in Brazil as liquid fertilizer (Ribeiro et al., 2013). However, the direct application of vinasse is constrained by its high salinity and high density. These issues can be mitigated through mixing the vinasse with other solid wastes. The environmental damage caused by discarding vinasse into the soil or running waters was an incentive to studies aiming to find alternative, economic applications for this residue. Results from such studies indicate that vinasse contributes to improvements in soil quality and agricultural productivity, if it would be properly used (Prado et al., 2013).

Though, many studies have been performed to identify the effects of vinasse application on growth, development and production of sugarcane and physical properties of soil (e.g. Tejada et al., 2009; Jiang et al., 2010; Prado et al., 2013; Ribeiro et al., 2013), but very limited studies were taken place to study the effects of application of vinasse on surface runoff and water soil loss rate. According to previous studies (Tejada and Gonzalez, 2006a, 2007; Tejada et al., 2006a, 2007), the application of beet vinasse had unfavorable impacts on some soil properties viz. structural stability, bulk density, ESP, microbial biomass, respiration, enzymatic activities. Tejada and Gonzalez (2006b) investigated the relations between soil erosion and erodibility (K) in a treated soil by cotton gin crushed compost (CC) and beet vinasse (BV) applied for 5 years on a Typic Xerofluvent. They demonstrated that an increase in dose of CC applied to the soil caused a decrease in K and soil loss, but when BV was applied, the soil physical and biological properties were declined. The results revealed that in the BV-treated soils under a rainfall with 45 min duration and 60 mm h^{-1} intensity, the K factor decreased by 6.4% at the end of the experiment compared to control soil. Madejón et al. (2001) also investigated the effect of three vinasse composts on crops (corn and sugar beet) and some chemical properties of a calcareous loamy sand soil. Their results indicated that the use of compost contributed to enhancing the level of organic matter in agricultural soils in SW Andalusia, Spain, which was particularly poor in organic matter. Characterization of vinasses from different feedstock sources by Espanã-Gamboa et al. (2011) showed the most appropriate treatments for the vinasses soluble solids conditioning. They verified that the vinasses could be safely used in agriculture without contaminating soil, underground water or crops, for energy recovery and animal feeding.

A review of the literature demonstrated the effectiveness of different organic amendments on growth, development and production of sugarcane and physical properties of soil as well. The literature review also clearly verified the variable behavior and effectiveness of different organic amendment, which necessitates further studies under different conditions and for other organic amendment. However, there was no comprehensive study on evaluation of the effect of vinasse amendment on runoff and soil loss control. In recent years, soil erosion has been extensively studied in laboratory using rainfall simulators. So that, the soil erosion plots and rainfall simulators are two important research equipments widely employed in erosion studies, worldwide. They allow producing runoff and occurring soil loss under repeatable and controlled conditions. In addition, the review of literatures has confirmed that the employ of different sized plots is practically applicable, logically economic and easily controllable and repeatable due to which their further utilizations have been advised with particular considerations (Sadeghi et al., 2012). On the other hand, there is several sugarcane agro-industry development companies in southwestern of Iran producing huge quantity of vinasse mainly discharges into adjacent rivers. The present study therefore examines the potential role of vinasse amendment on runoff and soil loss reduction on a silt loam soil collected from a summer rangeland, northeastern Iran using a simulated rainfall intensity of 72 mm h^{-1} and slope of 20%.

2 MATERIALS AND METHODS

2.1 Soil properties

The soil required for the study was provided from upper 30 cm of the soil surface layer from Badranlou area in Northern Khorasan Province, Iran, and transported to the laboratory. The area is mainly under dry land farming system and very prone to soil erosion. The texture of the study soil was silty loam (48% silt, 28% clay and 24% sand). The measured organic matter, pH, electrical conductivity and bulk density of the soil were 0.155%, 8.2, 137.3 µmohs cm^{-1} and 1.3 g cm^{-3}, respectively.

2.2 Plot preparation

Experimental plots with 0.5 m long, 0.5 m wide, and 0.3 m deep were used for the present study. The soil was then prepared for application and simulated in the plots using previously reported methods (Thompson and Beckmann, 1959; Loch and Donnollan, 1988; Kukal and Sarkar, 2011). The upper 10 cm of the soil was compacted by concrete roller to achieve the desired bulk density of 1.3 g cm^{-3} and similar to the field conditions. To establish the filter layer under the experimental soils, three layers of mineral pumice grains with different sizes with total thickness of 17 cm were packed. Based on the annual average soil moisture content, the soil was also treated to produce a moisture content of 33%.

2.3 Vinasse characteristics

Vinasse used for the experiment was produced by Research and Training Institute for the Industrial Development of Sugarcane in Khuzestan Province, Iran. The levels of vinasse application (0.5, 1 and 1.5 l m^{-2}) were selected based on information existed for application of vinasse for other purposes and other amendments, avoiding considerable environmental pollution due to high contents of N and K probably leading to high salinity and high density, feasibility of application and accessibility as well (Madejón et al., 2001; Tejada and Gonzalez, 2005, 2006a, 2006b; Tejada et al., 2007, 2009; Jiang et al. 2010; Maldonado et al., 2011). Three levels of 0.5, 1 and 1.5 l m^{-2} of vinasse were sprayed on soil surface in three replications and left for 24 h to increase the stability of vinasse layer on the soil surface and mimic the natural conditions.

2.4 Laboratory experiments

To evaluate the effectiveness of vinasse for runoff and soil loss control, laboratory experiments were conducted under a rainfall simulator at the Rainfall and Soil Erosion Simulation Laboratory of Faculty of Natural Resources of Tarbiat Modares University, located in Noor Campus, Mazandaran Province, Iran. The rainfall simulator consists of a 4000 L water tank and 27 precalibrated nozzles in three parallel lines designed to simulate raindrops of 1.0-1.3 mm average size. The drops fall from a height between 4 and 6 m at the upper and lower parts of the plot, respectively, reaching a 7 ms^{-1} speed the study plot (Gholami et al., 2013; Sadeghi et al., 2015a,b). The laboratory experiments were conducted at 20% slopes under simulated rainfall intensity of 72 mm h^{-1} with duration of 30 min almost corresponded with natural rainstorms of the study area. The rainfall intensity of 72 mm h^{-1} with duration of 30 min were considered corresponded with climatological condition in the origin of the soil obtained though IDF curves analysis for data collected from the nearest synoptic station (Bojnourd, Northern Khorasan Province in Northeast of Iran) with the return period of 50 years. The slope of 20% was selected based on the average slope of the original area where the soil was collected (Hazbavi, 2013; Hazbavi et al., 2013; Sadeghi et al., 2014). A general view of the experimental setup is shown in Fig. 1.

The sediment laden runoff was measured at different time steps of 2 to 5 min for the entire period of the experiments. The samples were then oven dried for 24 h at 105 ºC and corresponding sediment concentration and soil loss were determined. Also, the runoff commencement and cessation times were also recorded. The time of runoff commencement and cessation times, and regular measurement of runoff volume were measured by a chronometer and standard gauged cylinders, respectively (Gholami et al., 2013; Sadeghi et al., 2014; Sadeghi et al., 2015a,b, Sadeghi et al., 2016).

2.5 Statistical analyses

All analyses were performed on triplicate samples and subjected to analysis of variance (ANOVA). The data were tested for homogeneity of variances at a significance level of $P<0.05$ and probability values of less than 0.05 were then considered as statistically significant in one-way ANOVA. Significant means were subjected to analysis by Duncan's multiple range test ($P<0.05$). The SPSS V.19 software package was used for the statistical analyses.

3 RESULTS AND DISCUTION

3.1 Runoff

The variations of runoff and cumulative runoff volume with rainfall duration for various vinasse application rates are shown in Figs. 2 and 3. As it is seen in Figs. 2 and 3, the maximum and the minimum reduction in runoff generation occurred at 1 and 1.5 l m^{-2} levels of vinasse application, respectively.

The maximum and minimum runoff volumes were 21627.16 ml m^{-2} at control plot and 11884.040 ml m^{-2} at 1 l m^{-2} level of vinasse treated plot, respectively (Table 1). The results of the ANOVA test to assess the effect of vinasse on runoff volume under study condition have also been presented in Table 2. The ANOVA results showed that the effect of vinasse on runoff volume was not significant at a confidence level of 95% (P= 0.643), which is consistent with Madejón et al. (2001) who reported that single application of vinasse did not significantly influence runoff and erosion from simulated rainfall. The less runoff in 0.5 and 1 l m^{-2} vinasse-treated plots compared to control plot confirmed the previous observations of Bakr et al. (2012) for different soils of Louisiana, Gholami et al. (2013) and Sadeghi et al. (2015a,b) for sandy-loam soil of the Alborz Mountains who reported that the compost/mulch cover led to reduce runoff at plot scale. But more runoff in 1.5 l m^{-2} vinasse-treated plots in comparison with control plot verified changing effectiveness of vinasse on runoff control. It is due to water repellency phenomena, probably. The increased use of vinasse may affect water repellency and have the potential to be easily transported in surface runoff at high levels. Agassi et al. (1998) verified that the hydrophobic sound effects, which are common to a range of organic amendments, may decrease the infiltration rate in soil treated with sludge as organic amendment. This result persisted for a long time after the sludge has been used.

The runoff commencement and cessation times under different vinasse treatments are also shown in Fig. 4. The runoff commencement time was recorded at the onset runoff reached plot outlet. As it is seen in Fig. 4, vinasse increased the runoff commencement time about 2.25 times more compared to that reported for untreated plots. This is consistent with previous studies (e.g. Gholami et al., 2013; Sadeghi et al., 2015a) showing that some organic amendments promote runoff commencement time and delaying runoff. Also, vinasse decreased the runoff cessation time almost 0.9 times less compared to that reported for untreated plots. The maximum effectiveness for both variables occurred at 1.5 l m^{-2} level of vinasse application.

The effect of vinasse on runoff commencement and cessation times under study conditions was also statistically analyzed by ANOVA whose results have been given in Table 2. The results clearly showed that the effect of vinasse on runoff commencement and cessation times were highly significant at a confidence level of >99% ($P < 0.006$).

3.2 **Soil loss**

The average values of eroded soil under different vinasse treatments under experiment conditions have been shown in Fig 5. Fig. 6 also shows the cumulative variation of soil loss under different vinasse treatments. It was observed from the results that the vinasse treatments decreased soil loss rates during the entire period study except for [illegible]0th and 25th minutes of record for 0.5 l m^{-2} vinasse application. The application rate of 1 l m^{-2} performed better than other two treatments in reducing the amount of eroded soil from the plots. All three vinasse treatments produced less eroded soil in comparison with control plots.

Table 3 contains the specific values of average soil loss for vinasse treatments. The vinasse treatment at 1 l m^{-2} level produced, on average, less eroded soil. The results verified that the vinasse protected soil aggregates from the direct impact of rain drops and prevented soil detachment. It also helped to increase surface roughness preventing quick runoff generation. Tejada and Gonzalez (2006b and 2007) and Tejada et al. (2009) found that adding different organic wastes increased soil structural stability and decreased soil loss. Tejada et al. (2009) also reported, in particular, that the fresh beet vinasse application had a negative effect on the soil physical, chemical and biological properties. They stated that the fresh beet vinasse increased soil loss and decreased plant cover because of high quantities of monovalent cations of fresh beet vinasse such as Na^+. Tejada and Gonzalez (2008) further found that cotton gin crushed compost (CC) and poultry manure (PM) at the higher dose reduced soil loss under simulated rain at 140 mm h^{-1} by 29.2% and 25%, respectively, compared to the control soil. All the studied treatments reduced soil loss, especially in the plots treated with the higher concentration of organic matter. However, the CC treatments were more efficient than the PM treatments. In soils amended with beet vinasse a degradation of soil structure and increase on erosion were observed due to the enrichment of the cation exchange capacity by monovalent cations, such as K (Tejada and Gonzalez, 2006a; Tejada et al., 2007). High saturation of K in the cation exchange capacity may lead to soil dispersion and, consequently, to soil erosion and land degradation. In addition, whenever vinasse is applied to silty loam soil, a part of them fills up the voids of soil, and other part stays on the soil aggregates surface. The effects of vinasse may be temporary, since the organic compounds of vinasse are highly decompounds from vinasse cementing the micro aggregates and favoring the flocculation of clay fraction (Ribeiro et al., 2013).

The results of the ANOVA test to assess the effect of vinasse on soil loss are presented in Table 4. The results of ANOVA also showed that the effect of vinasse on soil loss was not significant at confidence level of 95% (P= 0.506), which agrees with Madejón et al. (2001). It is reported that depend upon the type, amount, size and dominant components of the added organic materials, the influence of organic matter on soil loss is different (Tejada and Gonzalez, 2006b, 2007). For instance, Tejada and Gonzalez (2005) showed that an increase in electrical conductivity caused by high vinasse application rate adversely affects soil total porosity, bulk density, and structural stability. Thus, soil physical properties can be influenced by vinasse application. These changes in soil properties can have a substantial impact on runoff and soil loss from fields where vinasse has been applied. Tejada et al. (2006) found that organic amendments improve soil structure because they promote the flocculation of clay minerals, which is important for soil particle aggregation.

The soil texture of the study area i.e. silty loam used in the vinasse application on soil loss analyses could also justify the hydrologic behavior of the study plots. Because of the limited number of study locations, it was not possible to identify the effects of textural characteristics on calculated runoff and soil loss ratios. As Ojeda et al. (2003) noted, the sandy and loam soils treated by 10 t ha^{-1} of dry matter of the sewage sludge differ in their susceptibility to runoff generation and soil erosion to soil amendments application. So that, for loam soil erosion increases with runoff. This would suggest that erosion on this type of soil could be limited by runoff transport.

4 Conclusions

The results of the study indicated that the single application of vinasse did not significantly influence on runoff and erosion. The results also revealed that the least amount of runoff and soil loss produced at 1 l m^{-2} of vinasse-treated silt loam soil. Vinasse composts can be then used as an alternative to mineral fertilizers and reduce soil erosion and water loss. Since the runoff and soil loss ratios from different plots and even under realities may be different from those obtained during present study, further researches are needed for better understanding the potential benefits and limitations of various applications of vinasse for sound management of water and soil and to allow drawing comprehensive conclusion. More and long term experiments are also needed for monitoring and evaluating long term effects of vinasse on soil hydrology and erosion processes with particular focus on environmental effects.

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Table 1. Runoff rate (ml m^{-2}) under different vinasse treatments in each study 0.25 m^2-plot

Vinasse rate (l m^{-2})		0 (Control)	0.5	1.0	1.5
Sample No.	1	17769.532	12699.720	11884.040	17679.116
	2	15354.972	16970.640	20086.312	20518.280
	3	21627.164	18646.160	15849.736	17445.804
Average		18250.556	16105.508	15940.028	18547.732

Table 2. Results of ANOVA on effect of vinasse on runoff volume, runoff commencement and cessation times

Variable	Comparison	Sum of Squares	df	Mean Square	F-value	Significance level
Total Runoff Volume (ml)	Between Groups	1069690.241	3	356563.414	0.583	0.643
	Within Groups	4895168.190	8	611896.024		
	Total	5964858.431	11			
Commencement time (min)	Between Groups	5.751	3	1.917	9.103	0.006
	Within Groups	1.685	8	0.211		
	Total	7.436	11			
Cessation time (min)	Between Groups	2.154	3	0.718	57.560	0.000
	Within Groups	0.100	8	0.012		
	Total	2.254	11			

Table 3. The soil loss amount under different vinasse treatments in each plot (g m^{-2})

Vinasse rate (l m^{-2})		**0 (Control)**	**0.5**	**1.0**	**1.5**
Sample No.	**1**	230.468	100.280	155.960	240.884
	2	325.028	269.360	241.688	241.720
	3	272.836	333.840	150.264	154.196
Average		276.112	234.492	182.636	212.268

Table 4. Results of analysis of variance of effect of vinasse on total soil loss

Variable	Comparison	Sum of Squares	df	Mean Square	F-value	Significance level
Total Soil Loss	Between Groups	872.170	3	290.723	0.848	0.506
	Within Groups	2743.181	8	342.898		
	Total	3615.351	11			

Figure 1. A general view of experimental setup at Rainfall and Soil erosion Simulation Laboratory of Tarbiat Modares University, Iran

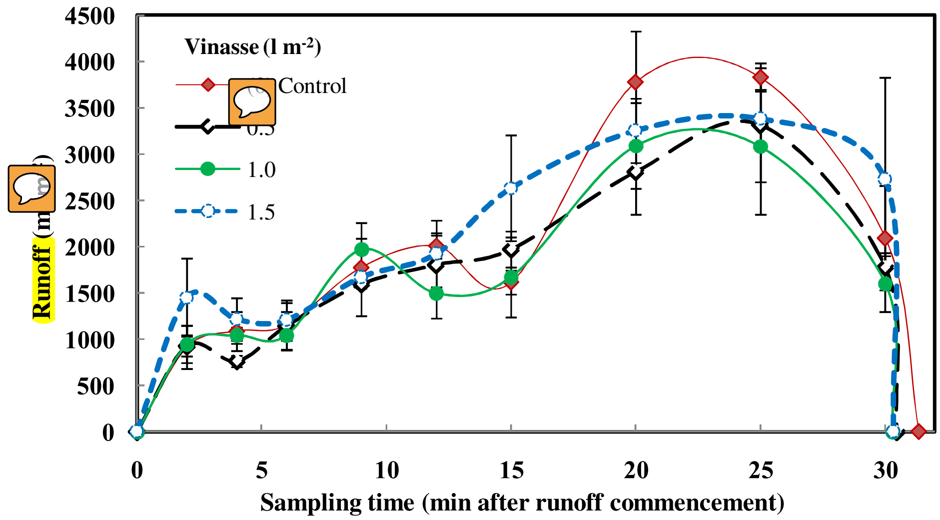

Figure 2. Variations of runoff volume under different vinasse treatments and under study conditions (0.25 m^2-small plot, rainfall intensity of 72 mm h^{-1} and experiment duration of 30 min)

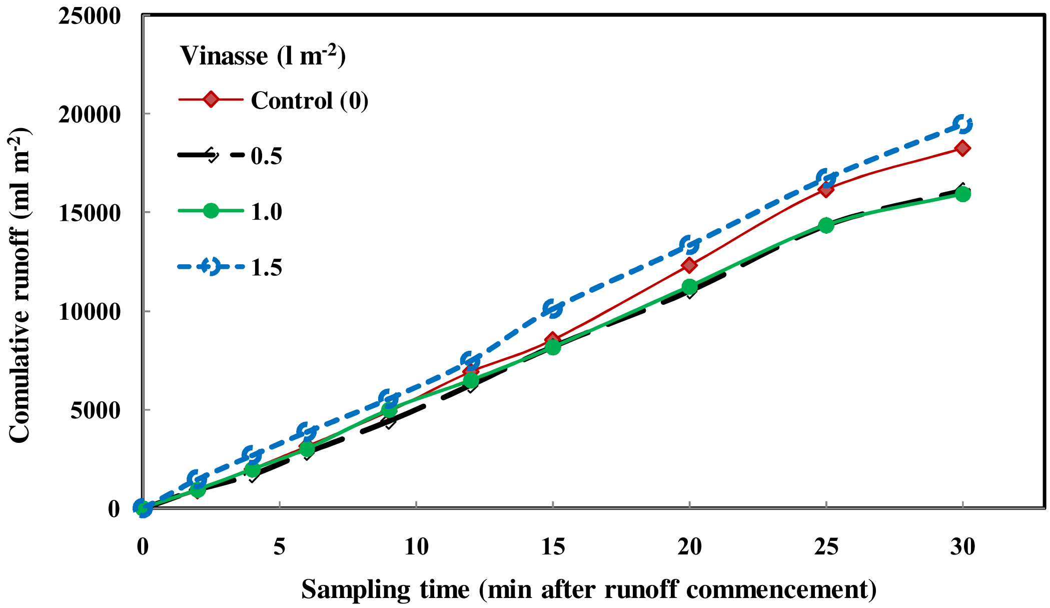

Figure 3. Variations of cumulative runoff under different vinasse treatments and under study conditions (0.25 m^2-small plot, rainfall intensity of 72 mm h^{-1} and experiment duration of 30 min)

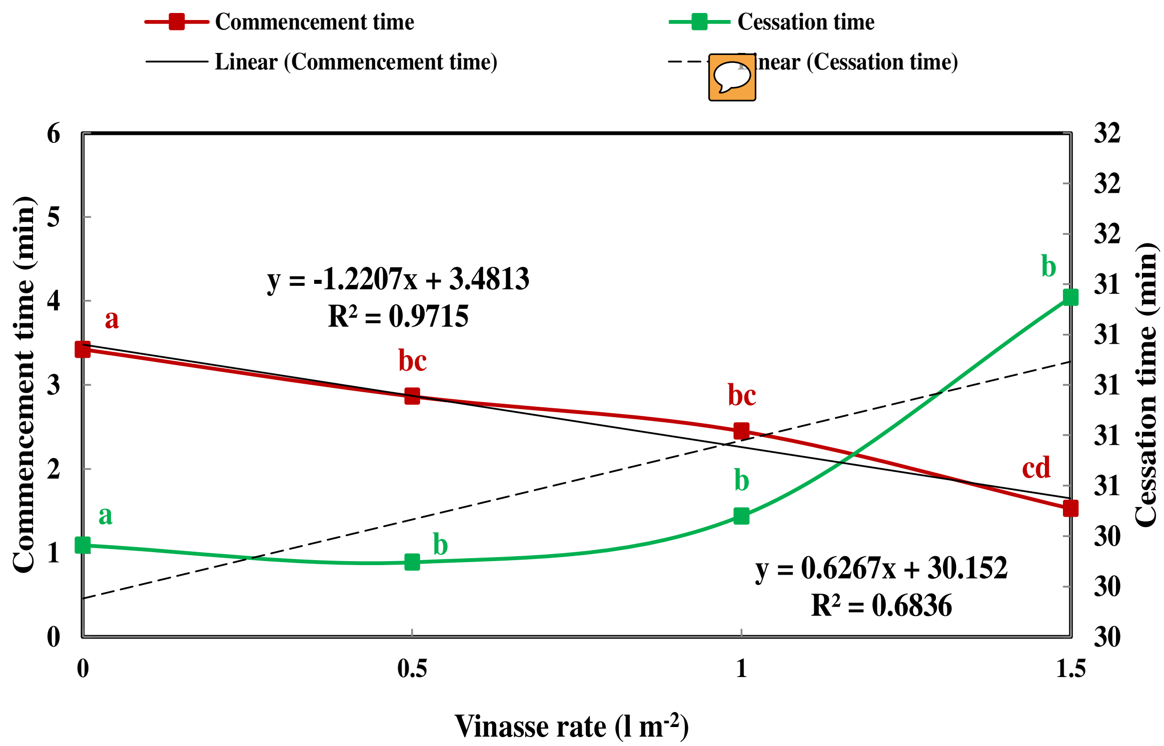

Figure 4. Runoff commencement and cessation times variation under different vinasse treatments and under study condition (0.25 m^{-2}-small plot, rainfall intensity of 72 mm h^{-1} and experiment duration of 30 min)

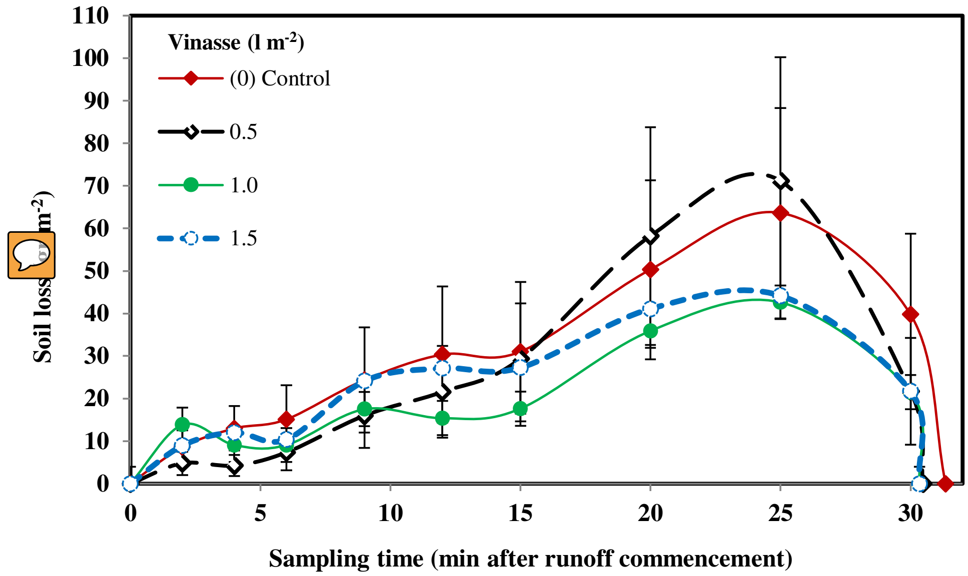

Figure 5. Variations of soil loss under different vinasse treatments and under study conditions (0.25 m^2-small plot, rainfall intensity of 72 mm h^{-1} and experiment duration of 30 min)

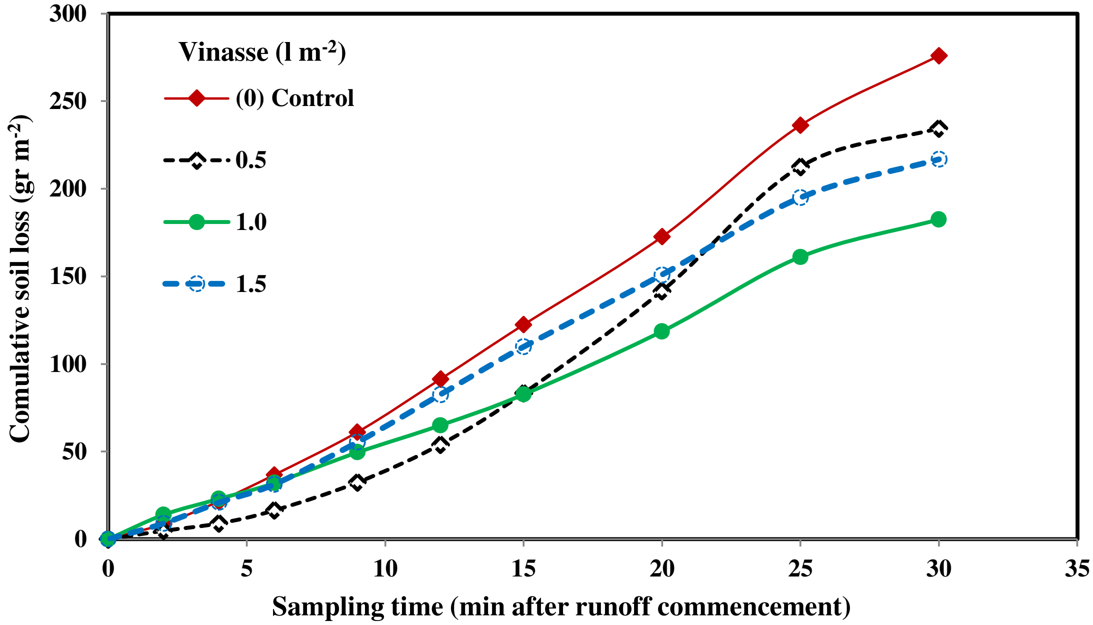

Figure 6. Variations of cumulative soil loss under different vinasse treatments and under study conditions (0.25 m^2-small plot, rainfall intensity of 72 mm h^{-1} and experiment duration of 30 min)