

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 content. Accordingly, the laboratory experiments were conducted by using 0.25 m²-experimental plots at 20% slope and rainfall intensity of 72 mm h⁻¹ with 0.5 h duration. The effect of vinasse was investigated on runoff and soil loss control. Experiments were then set up as a control (with no amendment) and three treated plots with doses of 0.5, 1, and 1.5 l m⁻² of vinasse subjected to simulated rainfall. Laboratory results indicated that vinasse at different levels could not significantly (P>0.05) decrease the runoff amount and soil loss rate in the study plots compared to untreated plots. 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. In conclusion ~~vinasse addition as soil amendment did not significantly affected runoff and soil loss. It is may be due to the development of a water repellency phenomena that led to a decrease in the water infiltration, following an increase in runoff volume. The increased in the runoff depth was led to reduction in soil resistance to rainfall and runoff detachments and availability of readily transportable sediments.~~

1 1 Introduction

2 Soil erosion is an environmental concern resulting in increased sedimentation, turbidity
3 and levels of pollutants in adjacent water bodies (Ebisemiju, 1990; Pieri et al. 2007; Girmay
4 et al., 2009; Bhattarai et al., 2011, Bakr et al., 2012). According to the Forest, Rangeland and
5 Watershed Management Organization of Iran, about 150 M US dollars are annually spent on
6 the watershed management projects implemented to prevent or to alleviate part of soil erosion
7 related problems in the country (Sadeghi et al., 2011). It led to erosion control technologies
8 receiving a great deal of attention to reduce soil erosion. Accordingly, soil erosion control has
9 principal importance in soil management and conservation in developing countries like Iran
10 (Newson, 2002; Haghjou et al., 2014). Besides that, soil management is important to crop
11 productivity, environmental sustainability and consequently human welfare.

12 Covering the bare soil with an appropriate material is one of the soil management
13 practices, which increases water infiltration and surface storage by enhancing the soil
14 structure and porosity. The layer of residues protects the soil against erosion, inhibits weed
15 germination, improves water retention, ameliorates physical and biological soil properties,
16 and is a source of plant nutrients (Sheoran et al., 2010; Araujo-Junior et al., 2013; Prado et al.,
17 2013). In addition, industrial processing of sugar cane to produce sugar and alcohol also
18 generates residues, such as filter cake and vinasse, which have a great potential for use in
19 agriculture as soil improvers and fertilizers (Prado et al., 2013). Meanwhile, to prevent soil
20 loss many organic soil improvers are mainly used (Tejada et al., 2009; Rigane and Medhioub,
21 2011). Additionally, according to Tejada et al. (2006a, 2006b), the general increasing of
22 biomass C in a soil can be associated to the constructive impact of organic materials on the
23 soil physical properties. The application of animal, industrial and municipal wastes is also
24 prevalent throughout the world as they can be an excellent source for nutrient and organic
25 matter (Bhattarai et al., 2011). Several studies have evaluated the effects of composted
26 organic wastes such as animal manure and sewage sludge compost on soil properties, quality
27 and productivity, dissolved organic carbon and nitrate leaching (e.g., Adler and Sikora, 2005;
28 Margesin et al., 2006; Bastida et al., 2007; Karami et al., 2012; Zornoza et al., 2013;
29 Eykelbosh et al., 2015), but there are relatively few studies (e.g., Tejada and Gonzalez,
30 2006b; Tejada et al., 2007; Tejada and Gonzalez, 2008; Gholami et al., 2013; Cerdà et al.,
31 2014a,b; Sadeghi et al., 2015a,b) on **evaluating the effect** of organic waste and residues on
32 runoff and soil loss control.

1 Application of organic amendment and mulches has already been proved as a method of
2 improving soil physical properties leading to affect runoff and soil erosion (Albaladejo et al.,
3 2000; Cerdà and Doerr, 2008; Cerdà et al., 2014a,b). Moreover, organic amendments are
4 increasingly being examined for their potential use in preventing soil losses (Tejada and
5 Gonzalez, 2008). There are a variety of organic amendments for soil management and
6 conservation, with different performance and mechanisms. In spite of that, different organic
7 amendments, viz. cotton gin crushed compost and poultry manure, beet vinasse, sewage
8 sludge, organic urban solid refuse, sheep manure, cow manure, rice husk, finely chopped
9 reeds, wheat straw, licorice (root) dregs (Agassi et al., 1998; Albaladej et al., 2000; Ojeda et
10 al., 2003; Tejada and Gonzalez, 2006b; Tejada et al., 2007; Tejada and Gonzalez, 2008;
11 Nicolás et al., 2012; Karami et al., 2012) have been used for soil conservation in agricultural
12 and forestry soils, commonly.

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

32 ~~Though, m~~any studies have been performed to identify the effects of vinasse application on
33 growth, development and production of sugarcane and physical properties of soil (e.g., Tejada

1 et al., 2009; Jiang et al., 2010; Prado et al., 2013; Ribeiro et al., 2013), but very limited
2 studies were taken place to study the effects of application of vinasse on surface runoff and
3 water soil loss rate. According to previous studies (Tejada and Gonzalez, 2006a, 2007; Tejada
4 et al., 2006a, 2007), the application of beet vinasse had unfavorable impacts on some soil
5 properties viz. structural stability, bulk density, **ESP**, microbial biomass, respiration,
6 enzymatic activities. ~~Madejón et al. (2001) investigated the effect of three vinasse composts~~
7 ~~on some chemical properties of a calcareous loamy sand soil.~~ Tejada and Gonzalez (2006b)
8 also investigated the relations between soil erosion and erodibility (K) in a treated soil by beet
9 vinasse (BV) applied for 5 years on a Typic Xerofluvent. **They demonstrated that when BV**
10 **was applied, the soil physical and biological properties were declined.** The results revealed
11 ~~that in the BV treated soils under a rainfall with 45 min duration and 60 mm h⁻¹ intensity, the~~
12 ~~K factor decreased by 6.4% at the end of the experiment compared to control soil.~~ **Their**
13 **results indicated that the use of compost contributed to enhancing the level of organic matter**
14 **in agricultural soils in SW Andalusia, Spain, which was particularly poor in organic matter.**
15 ~~Characterization of vinasses from different feedstock sources by~~ Espanã-Gamboa et al. (2011)
16 showed ~~the most appropriate treatments for the vinasses soluble solids conditioning.~~ They
17 ~~verified~~ that the vinasses could be safely used in agriculture without contaminating soil,
18 underground water or crops, for energy recovery and animal feeding.

19 A review of the literature demonstrated the effectiveness of different organic amendments
20 on growth, development and production of sugarcane and **soil physical properties** of soil as
21 **well.** However, there was no comprehensive study on evaluation of the effect of vinasse
22 amendment on runoff and soil loss control. In recent years, soil erosion has been extensively
23 studied in laboratory using rainfall simulators. So that, the soil erosion plots and rainfall
24 simulators are two important research equipments employed in erosion studies, worldwide.
25 They allow producing runoff and occurring soil loss under repeatable and controlled
26 conditions. **In addition, the employ of different** sized plots is practically applicable, logically
27 economic and easily controllable and repeatable due to which their further utilizations have
28 been advised with particular considerations (Sadeghi et al., 2012). **Researches** on vinasse are
29 in infancy stage and as such substantially more data are required before robust predictions can
30 be made regarding the effects of vinasse application to soils, across a range of soil, climatic
31 and land management factors. The present study therefore examines the potential role of
32 vinasse amendment on runoff and soil loss reduction on a silt loam soil collected from a

1 summer rangeland, northeastern Iran using a simulated rainfall intensity of 72 mm h⁻¹ and
2 slope of 20%.

3

4 **2 MATERIALS AND METHODS**

5

6 **2.1 Soil properties**

7 The soil required for the study was provided from the soil surface layer (0-30 cm) from
8 Badranlou area (57° 11' E and 37 ° 29' N) in Northern Khorasan Province, Iran, and
9 transported to the laboratory. The area is mainly under dry land farming system and very
10 prone to soil erosion. ~~Main climatic zone of this area is a cold substeppic of Irano-Turanian~~
11 ~~zone (slight Mediterranean affinities). Annual precipitation varies between 200-230~~
12 ~~and 450 mm. Very variable temperatures especially in winter, depending on altitude and~~
13 ~~latitude. In Iran, brown soils are common in Khorasan Province Based on World Reference~~
14 ~~Base reports (IUSS, 2014).~~

15 The collected soil was air-dried, passed through a 2 mm-sieve and analyzed for various
16 physicochemical properties. Soil texture was determined using the hydrometer method
17 according to Bouyoucos (1962). Soil organic matter (SOM) obtained by multiplying total soil
18 organic carbon by 1.724. Total soil organic carbon was measured by the Walkley and Black
19 wet dichromate oxidation method (Nelson and Somers, 1982). The pH and electrical
20 conductivity (EC) were determined in 1:2 soil:water suspension by pH and EC meters (Hati et
21 al., 2007). Bulk density at air dried moisture content was measured by Plaster (1985) method
22 (clod method). Properties of the study surface soil (0-30 cm) are shown in Table 1.

23

24 **2.2 Plot preparation**

25 Experimental plots with 0.5 m long, 0.5 m wide, and 0.3 m deep were used for the present
26 study. The soil was then prepared for application and simulated in the plots using previously
27 reported methods (Thompson and Beckmann, 1959; Loch and Donnollan, 1988; Kukal and
28 Sarkar, 2011). The upper 10 cm of the soil was compacted by concrete roller to achieve the
29 desired bulk density of 1.3 g cm⁻³ and similar to the field conditions. To establish the filter
30 layer under the experimental soils, three layers of mineral pumice grains with different sizes
31 with total thickness of 17 cm were packed. Based on the annual average soil moisture content
32 reported for the soil in the study area, the soil was also treated to contain a moisture content of
33 35% (Behzadfar et al., 2012; Hazbavi et al., 2013). After soil compaction, the plots were

1 established in water ponds for 12 h. Hence, **after extracting** the plots from **the** water ponds,
2 the vinasse was spread over the soil surface (Hazbavi et al., 2013; Sadeghi et al., 2015 and
3 **2016**).

4

5 **2.3 Vinasse characteristics**

6 Vinasse used for the experiment was produced by Research and Training Institute for the
7 Industrial Development of Sugarcane in Khuzestan Province, Iran. **pH** and EC of vinasse
8 were determined by pH and EC meters. Organic matter determined by dry combustion
9 method (MAPA, 1986). Calcium (**Ca**), **potassium** (K) and magnesium (Mg) were determined
10 **by atomic** absorption spectrometer after nitric and perchloric acid digestion. Chemical
11 Oxygen Demand (COD) **was determined** by closed reflux, colorometric method (APHA,
12 1998). The general properties of vinasse have been summarized in Table 2.

13 The levels of vinasse application (0.5, 1 and 1.5 l m⁻²) were selected based on information
14 existed for application of vinasse for other purposes and other amendments, avoiding
15 considerable environmental pollution due to high contents of N and K probably leading to
16 high salinity and high density, feasibility of application and **accessibility** (Madejón et al.,
17 2001; Tejada and Gonzalez, 2005, 2006a, 2006b; Tejada et al., 2007, 2009; Jiang et al. 2010;
18 Maldonado et al., 2011). Three levels of 0.5, 1 and 1.5 l m⁻² of vinasse were sprayed on soil
19 surface in three replications by a small manual pump and left for 24 h to increase the stability
20 of vinasse layer on the soil surface and mimic the natural conditions. To conduct the
21 comprehensive comparison, one control treatment (without vinasse) at three replications was
22 also applied. Urban tap water was used for the control treatment and the experimental setup
23 was used similar to that for vinasse treatments (Sadeghi et al., 2016).

24

25 **2.4 Laboratory experiments**

26 To evaluate the effectiveness of vinasse for runoff and soil loss control, laboratory
27 experiments were conducted under a rainfall simulator at the Rainfall and Soil Erosion
28 Simulation Laboratory of Faculty of Natural Resources of Tarbiat Modares University,
29 located in Noor Campus, Mazandaran Province, Iran. The rainfall simulator consists of a 4000

1 L water tank and 27 precalibrated nozzles in three parallel lines designed to simulate
2 raindrops of 1.3 mm average size. The drops fall from a height between 4 and 6 m at the
3 upper and lower parts of the plot, respectively, reaching a 7 ms⁻¹ speed (Gholami et al., 2013;
4 Sadeghi et al., 2015a,b). The laboratory experiments were conducted at 20% slopes under
5 simulated rainfall intensity of 72 mm h⁻¹ with duration of 30 min. The rainfall intensity of 72
6 mm h⁻¹ with duration of 30 min was considered representative of the climatological condition
7 of the origin of the soil, obtained through intensity–duration–frequency (IDF) curves analysis
8 for data collected from the nearest synoptic station (Bojnourd, Northern Khorasan Province in
9 Northeast of Iran) with the return period of 50 years. The slope of 20% was selected based on
10 the average slope of the original area where the soil was collected (Hazbavi, 2013; Hazbavi et
11 al., 2013; Sadeghi et al., 2014). A general view of the experimental setup is shown in Fig. 1.
12 For each event, the time to runoff initiation was recorded as the elapsed time between the start
13 of rainfall and the time at which surface runoff began entering the runoff collection container
14 located at the end of the plot. Runoff was sampled at different time steps of 2 to 5 min and its
15 volume was accordingly measured. The collection gutter at the lower end of each box was
16 protected by a shield to prevent rainfall from directly entering the collection container. The
17 amount of soil loss was then measured using a decantation procedure; oven-drying at 105 °C
18 for 24 h and weighing by means of high precision scale (Gholami et al., 2013; Sadeghi et al.,
19 2016). The runoff commencement and cessation times were also recorded. The time of runoff
20 commencement and cessation times, and regular measurement of runoff volume were
21 measured by a chronometer and standard gauged cylinders, respectively (Gholami et al.,
22 2013; Sadeghi et al., 2014; Sadeghi et al., 2015a,b).

23

24 **2.5 Statistical analyses**

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

31

32 **3 RESULTS AND DISCUSSION**

33

1 3.1 Runoff

2 The variations of runoff volume with rainfall duration for various vinasse application rates
3 are shown in Fig. 2 and Table 3. As it is seen in Fig. 2 and Table 3, the maximum and the
4 minimum reduction in runoff generation occurred at 1 and 1.5 l m⁻² levels of vinasse
5 application, respectively.

6 The average maximum and minimum runoff volumes were 18547.73 and 15940.03 ml m⁻²
7 at 1.5 and 1 l m⁻² level of vinasse treated plots, respectively (Table 3). The ANOVA results
8 showed that the effect of vinasse on runoff volume was not significant, which is consistent
9 with Madejón et al. (2001) who reported that single application of vinasse did not
10 significantly influence runoff and erosion from simulated rainfall. More runoff in 1.5 l m⁻²
11 vinasse-treated plots in comparison with control plot verified changing effectiveness of
12 vinasse on runoff control. It is due to water repellency phenomena, probably. The increased
13 use of vinasse may affect water repellency and have the potential to be easily transported in
14 surface runoff at high levels. Agassi et al. (1998) verified that the hydrophobic sound effects,
15 which are common to a range of organic amendments, may decrease the infiltration rate in
16 soil treated with sludge as organic amendment. This result persisted for a long time after the
17 sludge has been used.

18 The runoff commencement and cessation times under different vinasse treatments are shown
19 in Fig. 3. The runoff commencement time was recorded at the onset runoff reached plot
20 outlet. As it is seen in Fig. 3, the addition of 1.5 l m⁻² of vinasse accelerated the runoff
21 commencement up to 1.53 min, compared to control treatment with commencement time of
22 3.42 min. These results disagreed with previous studies (e.g., Gholami et al., 2013; Sadeghi et
23 al., 2015a) showing that some organic amendments promote runoff commencement time and
24 delaying runoff means more water infiltration. The addition of 1.5 l m⁻² of vinasse showed
25 runoff cessation time of 31.35 min, which was delayed compared to the control treatment
26 (30.36 min). The maximum effectiveness for both variables occurred at 1.5 l m⁻² level of
27 vinasse application. It means lower commencement time and higher cessation time involves
28 higher time with runoff, which is negative at reducing runoff to increase infiltration. In
29 conclusion, vinasse addition as soil amendment did not significantly affect runoff. It may be
30 due to the development of a water repellency phenomena that observed during the experiment
31 times led to a decrease in the water infiltration following an increase in runoff volume. In
32 addition, saturation of pores may be another reason to verify not significant effect of vinasse

1 ~~to decrease the runoff~~, since vinasse partly fills up the voids of soil, and partly remains on the
2 soil surface.

3 4 **3.2 Soil loss**

5 Table 4 contains the specific values of average soil loss for vinasse treatments. ~~In addition,~~
6 the average values of eroded soil under different vinasse treatments under experiment
7 conditions ~~have been~~ shown in Fig. 4. There was a trend showing decreased soil loss with
8 vinasse addition, but owing to the high variability, differences were not significant. ~~The~~
9 ~~results of ANOVA also showed that the effect of vinasse on soil loss was not significant at~~
10 ~~confidence level of 95% (P= 0.506)~~, which agrees ~~with~~ Madejón et al. (2001). ~~They reported that~~
11 ~~depend upon the type, amount, size and dominant components of the added organic materials,~~
12 ~~the influence of organic matter on soil loss was different (Tejada and Gonzalez, 2006b, 2007).~~
13 ~~For instance,~~ Tejada and Gonzalez (2005) showed that an increase in electrical conductivity
14 caused by high vinasse application rate adversely affected soil total porosity, bulk density,
15 and structural stability. Thus, soil physical properties could be influenced by vinasse
16 application under different conditions from those considered in the present study such as
17 different time scales and soil types. These changes in soil properties could have a substantial
18 impact on runoff and soil loss from fields where vinasse had been applied. Tejada et al.
19 (2006) found that organic amendments improved soil structure because they promoted the
20 flocculation of clay minerals, which was important for soil particle aggregation.

21 Tejada et al. (2009) reported, in particular, that the fresh beet vinasse application had a
22 negative effect on the soil physical, chemical and biological properties. They stated that the
23 fresh beet vinasse increased soil loss and decreased plant cover because of high quantities of
24 monovalent cations ~~of fresh beet vinasse~~ such as Na^+ . In soils amended with beet vinasse a
25 degradation of soil structure and increase on erosion were observed due to the enrichment of
26 the cation exchange capacity by monovalent cations, such as K (Tejada and Gonzalez, 2006a;
27 Tejada et al., 2007). High saturation of K in the cation exchange capacity may lead to soil
28 dispersion and, consequently, to soil erosion and land degradation. In addition, whenever
29 vinasse was applied to silty loam soil, a part of them filled up the voids of soil, and other part
30 stayed on the soil aggregates surface. The effects of vinasse might be temporary, since the
31 organic compounds of vinasse were highly decomposed from vinasse cementing the micro
32 aggregates and favoring the flocculation of clay fraction (Ribeiro et al., 2013).

4 Conclusions

The results of the study indicated that the single application of vinasse alone did not significantly influence runoff and erosion. Vinasse composts or mixed with other amendments 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 in the present study, further research is 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. Main original soil characteristics (n=3)

Soil property	Description
Soil texture	silty loam (48% silt, 28% clay and 24% sand)
Organic matter (%)	0.155
pH	8.2
Electrical conductivity ($\mu\text{mohs cm}^{-1}$)	137.3
Bulk density (g cm^{-3})	1.3

Table 2. Chemical characteristics of vinasse applied in the study

Property	Description
pH	5
Electrical conductivity ($\mu\text{S cm}^{-1}$)	1657
Organic matter (g kg^{-1})	100
Bulk density (g cm^{-3})	1.11
Ca (mg kg^{-1})	137.025
Mg (mg kg^{-1})	154.375
Chemical oxygen demand (g kg^{-1})	91.4
Moisture content (%)	93

Table 3. Average and standard deviation (Mean±SD) of runoff volume (ml) under different vinasse treatments in study 0.25 m²-plot

Vinasse rate (l m ⁻²)	0 (Control)	0.5	1.0	1.5
Mean ± SD	18250.6±3163.6	16105.5±3066.2	15940.0±4101.9	18547.7±1710.5
F-value	0.583 ns			

"ns", indicating non significant differences among study treatments (P> 0.05)

Table 4. Average and standard deviation (Mean±SD) of soil loss amount (g) under different vinasse treatments in study 0.25 m²-plot

Vinasse rate (l m ⁻²)	0 (Control)	0.5	1.0	1.5
Mean±SD	276.1±47.4	234.5±120.6	182.6±51.2	212.3±50.3
F-value	0.848 ns			

"ns", indicating non significant differences among study treatments (P> 0.05)



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

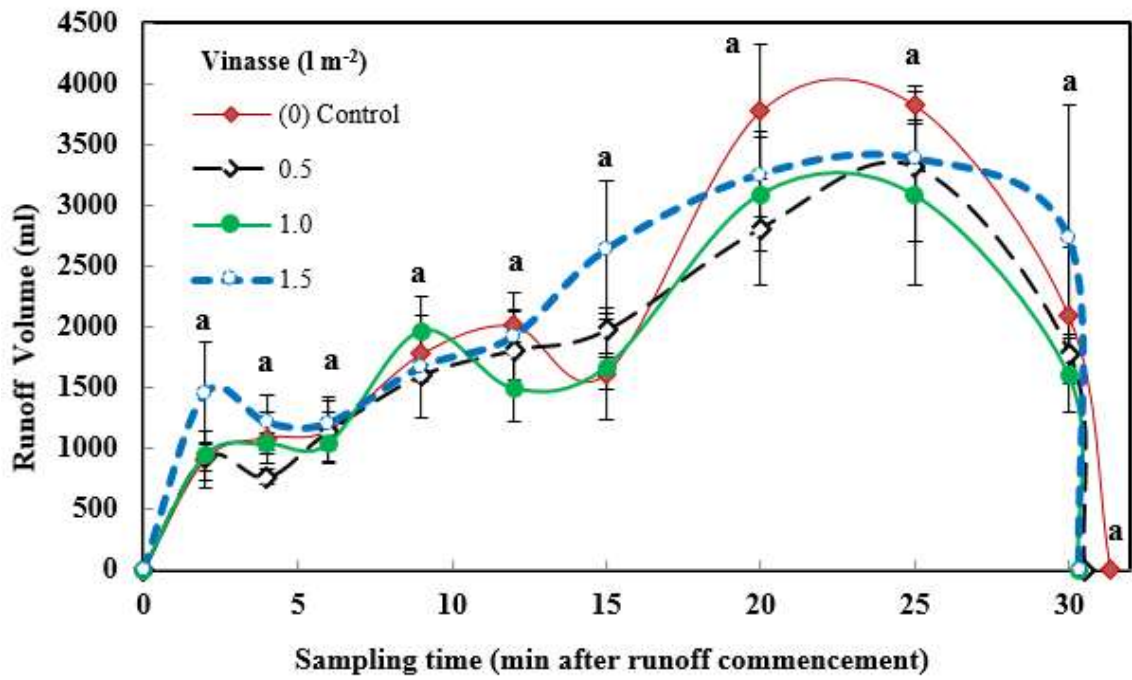


Figure 2. Variations of runoff volume per m² area under different vinasse treatments under study conditions (rainfall intensity of 72 mm h⁻¹ and experiment duration of 30 min). **same letters indicate non significant differences among study treatments (P > 0.05)**

یکی از این شکل‌ها را هر طور خودتان صلاح می‌دانید می‌توانید حذف بفرمایید.

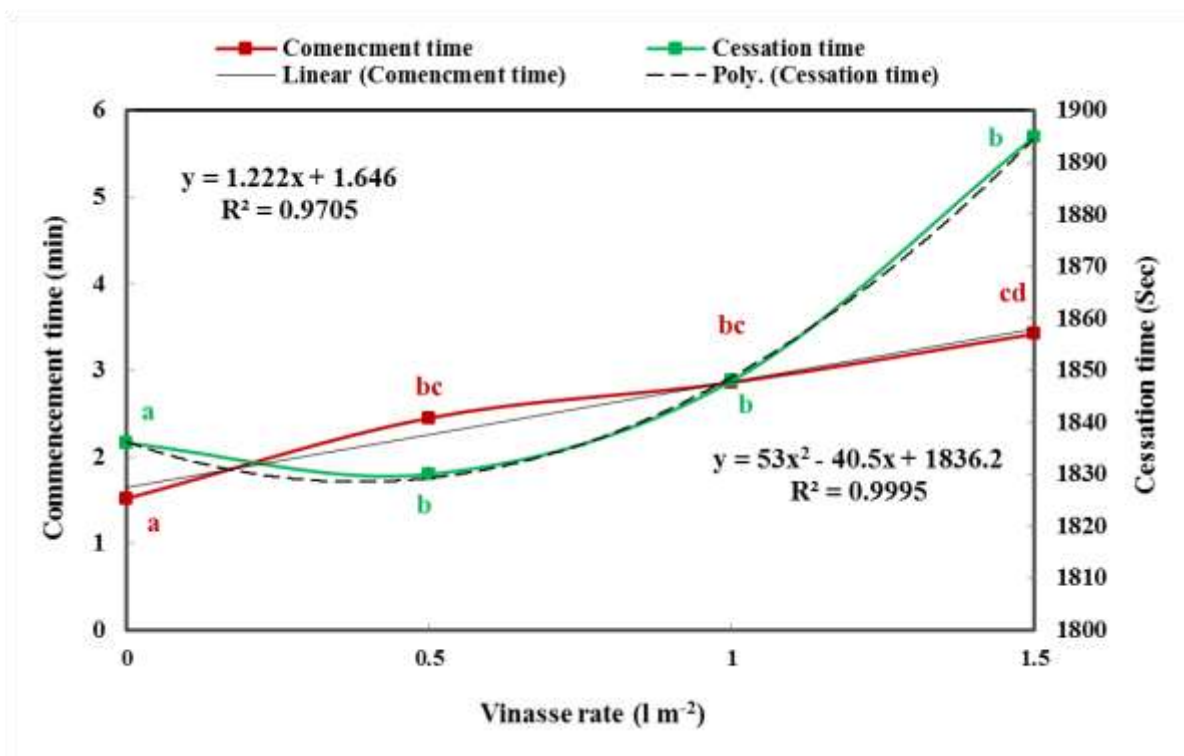


Figure 3. Runoff commencement and cessation times variation under different vinasse treatments and under study condition (0.25 m²-small plot, rainfall intensity of 72 mm h⁻¹ and experiment duration of 30 min). Different letters indicate significant differences among study treatments (P < 0.05).

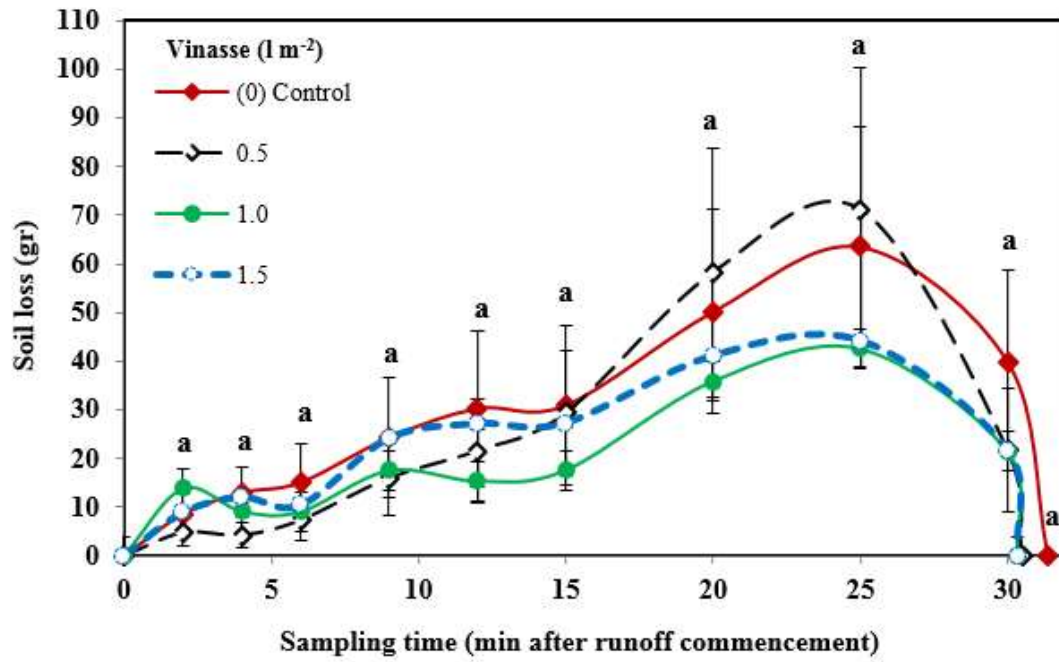


Figure 4. Variations of soil loss per m² area under different vinasse treatments under study conditions (rainfall intensity of 72 mm h⁻¹ and experiment duration of 30 min), same letters indicate non significant differences among study treatments (P> 0.05).