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The Effects of Slope and Zeolite Rates on Nutrient Losses in Sediment from Loess Soil during Simulated Rainfall

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ABSTRACT

This study was conducted to study the effect of zeolite and slope on sediment concentration, nutrient loss, and some hydraulic flow parameters in a loess soil of Northwest of Iran. The loess soil used for the experiments is collected from the surface layer (0-30 cm depth) and experiments were done using a rainfall simulator with three zeolite treatments (0%, 10% and 20%) and three slopes (15%, 30% and 45%). All experiments were conducted as a factorial with three replications at the rainfall intensity of 80 $mm.h^{-1}$. Data analysis, variance analysis, and mean comparison (through Duncan's test at $p<0.05$) were performed. The results of statistical analysis showed that the zeolite and slope had a significant effect on the sediment discharge, runoff discharge and sediment concentration ($p<0.01$). Sediment discharge in the control and in the slopes of 15, 30 and 45% was in order 7.22, 50.61 and 77.09 $gr.m^{-1}.s^{-1}$ and in 10% and 20% zeolite was 6.31, 43.60 and 54.96 $gr.m^{-1}.s^{-1}$ and 6.81, 42.06 and 52.27 $gr.m^{-1}.s^{-1}$ respectively. The amount of nitrogen in the sediment varied between 0.3 and 0.41 percent. Phosphorus content in sediments was between 13 and 22 ppm and potassium evaluated 300 to 470 ppm. The highest content of nitrogen, phosphorus, and potassium in the sediment was observed at the 0% zeolite and 45% slope. Our results suggest that zeolite can be considered as an effective modifier of soil physicochemical properties and lead to better protection of soil in the loess regions.

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1. Introduction

One of the problems that humans have faced since the beginning of agriculture on earth is the rapid rate of soil erosion by wind and water (Ma and Li, 2011). Currently, 36% of the world's agricultural land is losing topsoil, which is putting our food security at risk (Huo *et al.*, 2020). Soil erosion is a problem in the semi-arid regions of the world, and is considered a dangerous issue in countries with temperate climates. Yang *et al.* (2021) stated that erosion involves processes where soil is washed away, loosened, dissolved, or removed from the part of the land, and includes the processes of leaching, solubility, and transport and topographical position and slope causes the creation of hydrological regimes and various types of erosion (Huang *et al.*, 2013). The intensity of water erosion in a region is affected by geological characteristics, climatic conditions, elevation, soil properties, land use, social, economic, and political factors. Meanwhile, the importance of slope is greater than the other factors. This problem is very serious in Iran, where a large part of it is covered by hills and experienced land use change (Cook *et al.*, 2006).

Annual soil loss in Iran is estimated at 2 to 2.5 billion tons, and the erosion rate exceeds 15 tons per hectare (Behzadfar *et al.*, 2017). Also, sedimentation resulting from erosion contributes to water pollution. Sediment causes environmental problems such as the destruction of aquatic animals, reduction the diversity of fish and shellfish, penetration of sunlight into the water, and consequently reduction of the photosynthesis of plants. Another very harmful effect of erosion is the loss of soil nutrients through the runoff and sediment (Ramos and Martinez-Casasnovas, 2006). Research about sedimentation is very important for watershed management, sediment discharge of reservoir dams, and issues related to the preservation and expansion of water resources. Also, studying the runoff as one of the main processes of soil erosion is essential, but measuring the rate of soil erosion and its processes under natural rainfall conditions is time-consuming and costly (Boulange *et al.*, 2019).

To study the erosion processes in lab, new methods that are both economical and appropriate should be used (Galloway *et al.*, 2003). One of the methods for studying the factors affecting erosion and sedimentation is to simulate rain and runoff. Among the devices used in runoff simulation methods is the flume. A large number of researchers have used flumes of different dimensions for research in the field of water erosion and its modeling (Rose *et al.*, 2007; Abudi *et al.*, 2012). In the research conducted by Defersha *et al.* (2012) using a rainfall simulator regarding the effect of soil type, organic matter, slope and the interaction of these three factors on permeability, runoff, and splash erosion, one method to control erosion is using materials that improve the stability of soil. These materials placed between the soil particles, increase the connection between them and make a porous structure. One of these modifying materials is zeolite.

Zeolites are hydrated aluminosilicate crystals that affect cation exchange capacity and adsorption properties of soil. The benefits of using zeolite in agriculture include improving the quantitative and qualitative properties of soil, reducing soil moisture loss, increasing phosphate absorption in sandy soils, reducing soil nitrogen leaching due to irrigation and rain, increasing soil ventilation, and providing oxygen (Wang *et al.*, 2016). This material improves the water retention and drainage capacity of the soil. Also, the investigations have shown that zeolite is an organic fertilizer that gradually releases its nutrients. Behzadfar *et al.* (2017) reported that the use of zeolite treatments caused a significant reduction in the volume of runoff, drainage water, and sediment compared to the control ones. These researchers showed that the use of zeolite plays an important role in controlling runoff and preventing damage to soils affected by the freeze-thaw cycle. The pieces of research showed that zeolite can reduce the effects of the freeze-thaw cycle and the main hydrological variables of the soil (runoff and sediment production) (Atashpaz *et al.,* 2024). Therefore, the use of zeolite as an effective modifier for controlling the soil erosion in sloping rangeland and degraded soils is recommended. Considering the erosion-sensitive loess soils of Golestan Province of Iran and the damages caused by it, this study conducted to determine the rate of erosion and sediment produced from a loess soil (Maraveh Tappeh), the effect of different content of zeolite on the reduction of its sedimentation, the effect of different amount of zeolite on the loss of nitrogen, phosphorus, and potassium nutrients, and also to determine the effect of slope on the loss of soil and nutrients.

2. Material and Methods

2.1. study area

Soil sampling was carried out from a depth of 0 to 30 cm from the soil surface in agricultural lands of the Maraveh Tappeh region (55°37′N and 55°29′E), Golestan Province (Fig. 1). The average annual rainfall and temperature in the study area are 147 mm and 16.5°C, respectively. Soil samples were air-dried and sieved through a 10-mm mesh" (early section). "Studied" is redundant; "passed through" is less precise than "sieved. Then, some of the samples were transferred to the laboratory for physical and chemical analysis. The zeolite used in this research was obtained from the Siah Zagh mine of Semnan. Also, zeolite was spread on the soil in the form of a strip, then mixed with it and incubated for a period of time (one week for each treatment) to allow the soil to react with the zeolite.

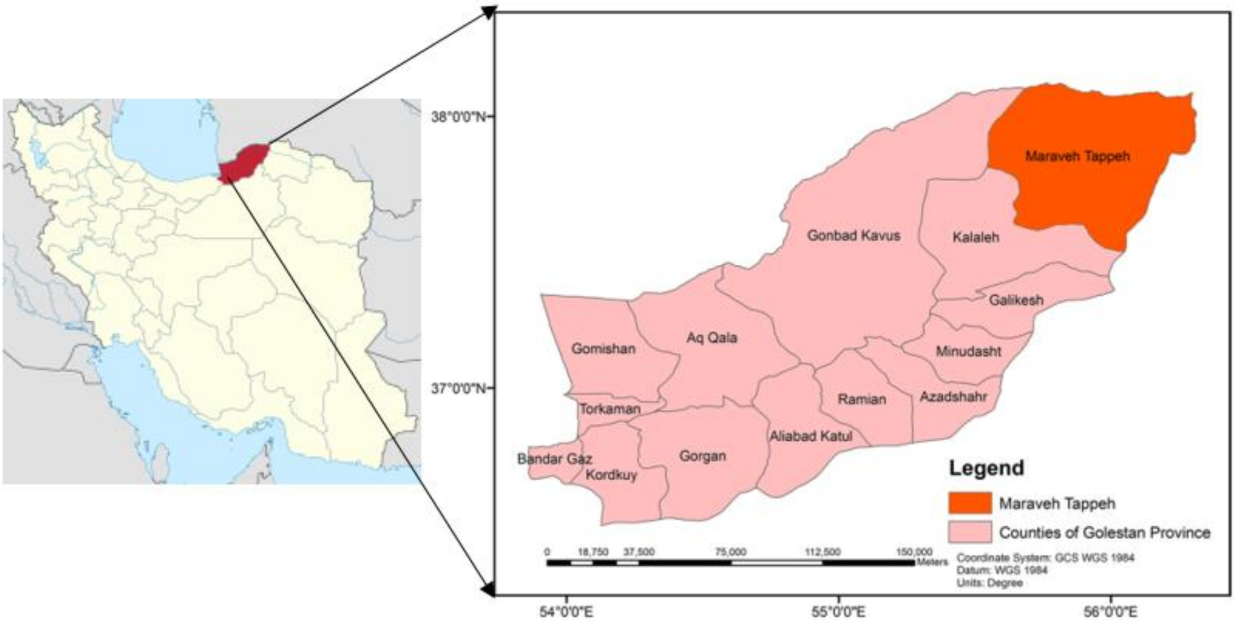

Fig. 1. Location of the study area

2.2. Physico-chemical properties

In the laboratory, the physical and chemical properties of the studied soil were measured according to the following instructions. The pH of the soil was measured in the saturated paste using a digital pH meter (model PH700 Benchtop pH Meter) (in the ratio of 1 to 5 soil to water). soil EC was determined in the saturated paste and in the ratio of 1 to 5 soil to water using an EC meter (Hanna Instruments, Model HI5321-02). Cation exchange capacity (CEC) was determined by the Aprile and Lorandi (2012) method. The Soil texture was measured by the hydrometric method after the oxidation of organic matter (Gangwar and Baskar, 2019). Soil organic carbon was determined by Walkley and Black (1934) method. The calcium carbonate of the soil was measured by neutralization method using hydrochloric acid and titration with NaOH (Shahbazi, 2020). Total soil nitrogen was measured by the Kjeldahl method, through three stages of digestion, distillation, and titration (Sáez-Plaza *et al.,* 2013). Phosphorus was measured by Olsen's method. After extraction and coloring were done, then the amount of phosphorus was read by a spectrophotometer at a wavelength of 720-880 nm (Olsen, and Sommers, 1982). Soluble potassium determination was carried out by flame photometry technique (Hendershot *et al.,* 2007).

2.3. Experimental design

The rain simulator used in this study was a pressurized type. Also, to measure the rainfall intensity, 36 containers with a circular cross-section of 11 cm in diameter were used, and then rainfall intensity was calculated in millimeters per hour. A flume was used to conduct the experiments. This metal flume had 2 meters long, 1-meter-wide, and 1-meter-high, which could be used to simulate different flow gradients (Fig. 2). The duration of each experiment was 45 minutes, and sampling was carried out at intervals of 1, 5, 10, 15, 20, 25, 30, 35, 40 and 45 minutes, depending on the start time of runoff. After each experiment, the samples containing of runoff and sediment were measured by a digital scale, poured into metal cans with a certain weight, and transferred to an oven. The samples were placed in the oven for 24 hours at 105°C, and after drying, the weight of sediment and runoff was measured. Volumetric was used to measure the flow rate of runoff. In this way, at the distance of 1 meter from the end of the flume. This was done for each experiment in 4 repetitions at 5, 15, 30 and 45 minutes from the start of the runoff.

Fig. 2. The flume used in this research

2.4. Statistical analysis

All experiments were conducted as a factorial in a completely randomized design with three replications at the rainfall intensity of 80 mm.h^{-1}. The first factor was the content of zeolite with three levels of 0, 10, and 20% by weight, and the second factor was the bed slope with three levels of 15, 30, and 45%. Data analysis, variance analysis, and mean comparison (through Duncan's test at $p<0.05$) were performed using the SPSS 16 software.

3. Results and Discussion

The physical and chemical characteristics of the studied soil are shown in Table 1 and the zeolite in Figure 3. The studied soil had a 23.48% sand, 25.85% clay, and 50.67% silt and the silt fraction being more abundant than other two particles. This soil according to the USDA classification (2010), had a silty loam texture. These soils are classified as erosion-sensitive soils (Arshad *et al.*, 2019).

Table. 1. Some physical and chemical properties of the studied soil

Parameter	Unit	Value
EC	dS.m^{-1}	24.2
pH	-	7.28
CEC	Cmol($^{+}$)/kg	16.54
Organic Carbon	%	0.195
sand	%	23.48
silt	%	50.67
clay	%	25.85

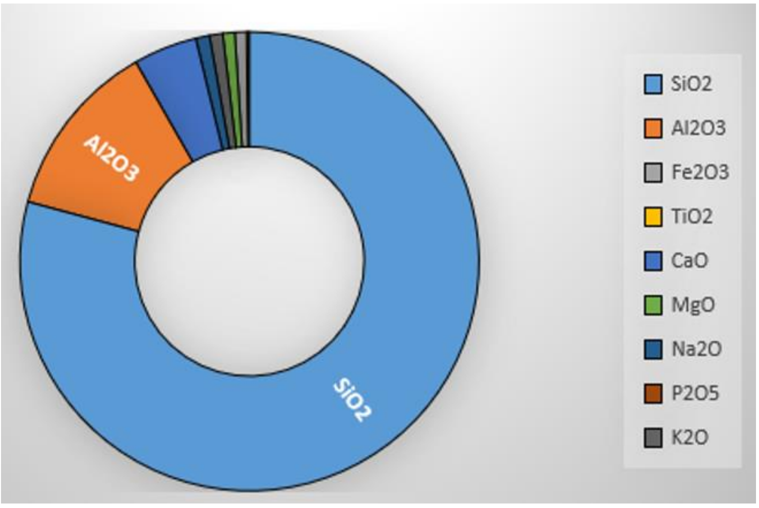

Fig. 3. The components of Zeolite.

3.1. The effect of zeolite and slope on the amount of sediment produced

The results of variance analysis (Table 2) showed that the effect of different levels of zeolite and bed slope on sediment and runoff concentration and flow rate were significant at $p<0.01$.

The effect of zeolite and slope on sediment discharge is shown in Table 3. According to this table, at the constant zeolite content, sediment flow rate increased with increasing slope.

Sediment discharge in the control treatment at slopes of 15%, 30%, and 45% was 7.22, 50.61, and 77.09 $g.m^{-1}.s^{-1}$, respectively, and in 10% and 20% zeolite was 6.31, 43.60 and 54.96 $gr.m^{-1}.\ s^{-1}$ and 6.81, 42.06 and 52.27 $gr.m^{-1}.\ s^{-1}$ respectively. Also, with increasing the zeolite concentration (0% to 20%), the sediment concentration decreased significantly at $p<0.05$ (Table. 3). These findings were consistent with the results of Ma and Li (2011) and Pan and Shangguan, (2006). They reported that by adding amendments to silty loam soil, the erosion rate and consequently the sediment discharge are reduced. Also, Abudi *et al*. (2012) stated that sandy soils are more sensitive to separation and transport by erosive agents due to their lower cohesion. Qiu *et al.* (2018) reported that with increasing slope, the flow rate of runoff sediment increased significantly. They showed that with increasing slope, the erosive power of runoff increased significantly and the runoff discharge increased that this increasing was more severe at higher rainfall intensities. Also, the results of our study were consistent with the findings of BehzadFar *et al.* (2017). They stated that by adding zeolite to sandy soil, the erosion rate and sediment concentration decreased.

Table. 2. Analysis of variance of factors (zeolite and slope) affecting on Sediment and runoff

Sediment Discharge	Sediment Concentration	Runoff Discharge	Degree of Freedom	Source of Variation
1010.7**	834.3**	756.2**	2	Zeolite (A)
987.6**	1101.3**	1327.1**	2	Slope (B)
763.2**	865.2**	987.3**	4	A*B
344.9	439.2	534.2	18	Error
13.2	11.1	15.3	-	Coefficient Variation

** Significant at 0.01 probability level.

According to Table 3, the runoff discharge decreased significantly ($p<0.05$) with increasing zeolite concentration and increased with increasing slope. The highest runoff discharge (0.6 $cm^3.s^{-1}$) was observed at a slope of 45% in the control treatment of zeolite (0%), and the lowest one (0.021 $cm^3.s^{-1}$) was observed at the slope of 10% and zeolite 20%. These results were consistent with those of Zhu *et al.* (2010) and Leh *et al.* (2013). Also, Mamedov *et al.* (2006) reported that the use of zeolite not only saved water but also reduced water shortages, the severity of runoff and flood damage.

Table. 3. Mean comparison of sediment and runoff characteristic in different treatments of zeolite and slope

Runoff Discharge(cm3/s)	Sediment Concentration(kg/m3)	Sediment Discharge(gr/m.s)	Slope (%)	Zeolite (%)
0.023^{a}	28.98^{a}	7.22^{a}	15	
0.04^{b}	262.37^{b}	50.61^{b}	30	0
0.6^{d}	427.59^{d}	77.09^{d}	45	
0.022^{a}	30.23^{a}	6.31^{a}	15	
0.02^{b}	225.35^{b}	43.6^{b}	30	10
0.4^{d}	289.63^{c}	54.96^{c}	45	
0.021^{a}	28.67^{a}	6.81^{a}	15	
0.02^{b}	211.71^{b}	42.06^{b}	30	20
0.25^{c}	229.48^{b}	52.27^{bc}	45	

Different letters in each row indicate significant differences at $p<0.05$ according to Duncan's test.

3.2. The effect of zeolite and slope on the loss of nutrients in the sediment

The results of variance analysis of the effect of slope and zeolite on nitrogen, phosphorus and potassium concentration in the sediment are presented in Table 4. Accordingly, the degree of slope and the amount of zeolite have a positive and significant ($p<0.01$) effect on the content of nitrogen, phosphorus and potassium in the sediment.

Table. 4. Analysis of variance for nutrient loss by sediment in different treatments

Sediment Available Potassium	Sediment Available Phosphorus	Sediment Total Nitrogen	Degree of Freedom	Source of Variation
950.7**	74.3**	36.2**	2	Zeolite (A)
37.6**	601.3**	247.1**	2	Slope (B)
33.2**	15.2**	77.3**	4	A*B
94.9	89.2	64.2	18	Error
20.2	15.1	16.3	-	Coefficient Variation

** Significant at 0.01 probability level

The amount of nitrogen in the sediment varied between 0.3 and 0.41 percent. Also, according to Table 5, the phosphorus content in the effluent sediments was between 13 and 22 ppm and potassium ranged from 300 to 470 ppm. Among the three nutrients studied (nitrogen, phosphorus, and potassium), potassium showed the highest and nitrogen the lowest loss. The loss of these three nutrients studied increased and decreased, respectively, with increasing slope and zeolite concentration. The results of our studies were consistent with Lin *et al.* (2010). On the other hand, the characteristics of nutrient loss due to their different binding with soil particles provide suitable information for controlling runoff and nutrient loss. Also, Wu *et al.* (2018) found that nutrients are significantly correlated with slope degree and that the rate of nutrient loss increases with increasing slope, which is consistent with the results of our study.

Table. 5. Mean comparison for nutrient loss by sediment in different treatments

Sediment Total N (%)	Sediment Available Phosphorus (ppm)	Sediment Available Potassium (ppm)	Slope (%)	Zeolite (%)
0.36^{bc}	18^{b}	450^{a}	15	
0.39^{b}	19^{ab}	460^{a}	30	0
0.39^{b}	22^{a}	470^{a}	45	
0.5^{a}	11^{d}	320^{bc}	15	
0.4^{ab}	14^{c}	350^{b}	30	10
0.3^{c}	15^{c}	340^{b}	45	
0.3^{c}	15^{c}	360^{b}	15	
0.4^{b}	20^{a}	350^{b}	30	20
0.22^{d}	16^{c}	320^{bc}	45	

Different letters in each row indicate significant differences at $p<0.05$ according to Duncan's test.

4. Conclusion

In this research, sediment concentration, runoff discharge, runoff sediment and loss nutrients (N, P and K) from the loess soil with different concentrations of zeolite (0%, 10% and 20%) and degrees of slope (15%, 30% and 45%) under the simulated rainfall condition were evaluated. The results showed that with increasing the concentration of zeolite and decreasing the degree of slope, all mentioned parameters decreased and we saw lower nitrogen, phosphorus, and potassium losses in the 20% zeolite and 15% slope treatments compared to the other study treatments. According to the results of this study, the treatment of 20% zeolite was successful in reducing sedimentation and loss of nutrients. Therefore, the results of this study can be tested on the other erodible soils of Golestan province with different textural classes to confirm and expand the results of this research.

Author Contributions

Conceptualization, Farshad Kiani and Ahmad Khaled Yagoubi.; methodology, Farshad Kiani; software, Farshad Kiani.; validation, Farshad Kiani., Ahmad Khaled Yagoubi.; formal analysis, Ahmad Khaled Yagoubi; investigation, Farshad Kiani.; resources, Farshad Kiani.; data curation, Farshad Kiani.; writing—original draft preparation, Farshad Kiani.; writing—review and editing, Farshad Kiani.; visualization, Farshad Kiani.; supervision, Farshad Kiani.; project administration, Farshad Kiani.; funding acquisition, Farshad Kiani. All authors have read and agreed to the published version of the manuscript.
All authors contributed equally to the conceptualization of the article and writing of the original and subsequent drafts.

Data Availability Statement

Data available on request from the authors.

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Ethical considerations

The authors avoided from data fabrication and falsification.

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Conflict of interest

The authors declares no conflict of interest.

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