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Investigating the methods of increasing the resistance of loess soils to prevent their settlement by using biological and mineral amendments

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ABSTRACT

Loess is a sedimentary deposit composed largely of silt-size grains that are loosely cemented by different materials. . Therefore, this study was conducted with the purpose of applying bentonite, lime, cyanobacteria, zeolite and red clay in stabilization of loess soils. These treatments were mixed in a laboratory flume with dimensions of 300 x 75 x 75 cm and were exposed to the runoff by mixing specific percentages (10% bentonite, 10% lime, 10% zeolite, 100gr per square meter cyanobacteria) with the regional soil. To investigate the erosion reduction treatments, the mean weight diameter (MWD), geometric mean diameter of soil (GMD) and the sediment content of erosion were used. The results showed that lime treatment had the greatest effect on two parameters of soil include MWD and GMD compared to other treatments. Also, the cyanobacteria and red clay had no significant effect on the soil MWD compared to control treatment. Therefore, lime treatment with three times increase, had the greatest effect on soil MWD. After that, bentonite and zeolite increased the mean weight diameter of soil by 2.1 and 1.5 times, respectively, compared to the control treatment. Lime found to increase the consistency and stability of the soil, while I being cheap and easily available and can be used on a large scale. Therefore, lime was introduced as the most effective treatment that can create a good connection between this sensitive soil particles and decrease considerably soil erosion as well as dust with their fixation that is an important challenge in the study area.

Keywords: Loess soil, water and wind erosion, mineral amendments, biological amendment, runoff.

1. Introduction

A loess is a clastic, predominantly silt-sized sediment that is formed by the accumulation of wind-blown dust (Frechen, 2011). Ten percent of Earth's surface is covered by loess (Vasiljevic et al., 2011). Therefore, the investigation of loess soils is so important with regard to the expansion of these soils, the design of dams, irrigation canals, development of urbanization and water and sewage (Derbyshire, 2001).

Loess deposits in the dry regions and cause significantly soil volume reduction or compaction when saturated. The settlement of these soils due to saturation leads to decrease in the carrying capacity of soils in arid and semi-arid regions. These soils are scattered in the north-east part of Iran (Management and Planning Organization of Iran, 2003). If the moisture content of these soils increases, their structure collapses and in addition to reducing the bearing capacity, they have a great settlement. The high settlement and reduction of bearing capacity can cause problems for dam foundations as well as structures (Iranian National Committee for Large Dams, 2014). In order to predict settlement several factors should be considered, such as the handling of the sample, the content of initial moisture, the extent and depth of wetting, the content of potential settlement of subsoil and the sensitivity of structure to settlement (Pawlak, 1998). Reducing the risk of damage during construction is always cheaper than the future repairs, and this phenomenon should be tackled. On the other hand, the possibility of soil improvement for projects depends on the site conditions, structure specifications, operational considerations, economic status and the level of risk-taking (Houston et al., 2001). There are various methods to improve the structure of loess soils, which include: saturating these soils, dynamic compaction, injection and stabilization them as well as control water surface (Akbari Gorgani, 2013).

One way of stabilizing the fine-grained soils like loess is amending it with bentonite, and with this method, the plasticity index of the soil increases. Bentonite is a clay mineral of the montmorillonite family with expansion properties that is formed by the weathering of volcanic ash (Gueddouda et al., 2008). The structural units of this clay include two tetrahedral sheets of silica, which cover an octahedral sheet of alumina. Bentonite, due to its unique properties, can be useful in increasing the plasticity index of soils. In the research conducted by Gueddouda et al., (2008), the effect of using seven different types of bentonites on the permeability characteristics of five soils with different grain sizes was investigated. They concluded that the use of 15% bentonite mixed with 85% sand has increased the stability of soil region.

Mishra et al., (2010) evaluated the effect of physical and chemical properties of bentonite, including liquid limit, expansion and sodium exchangeable percentage on soil consolidation parameters (t, CC, CV). They concluded that the use of 10% bentonite has increased soil stability.

The second way for rehabilitating these soils is to combine them with chemical agents such as lime. This factor is usually potential receptors that effectively connect soil compounds. Therefore, with addition of lime, soil characteristics such as particle size distribution is improved and the excessive contraction and expansion of the soil is controlled (Ajayi, 2012). Also, lime is added to soil in certain percentages as a common and cheap technique to improve the soil characteristics (Farooq et al., 2011).

The 3th solution is to use a green and environmentally biological ammendments (cyanobacteria) (DeJong et al., 2010). In recent years, autotroph species are used to stabilize the silty and sandy soils. For example, different species of Cyanobacteria has been considered due to grow in harsh environmental conditions in terms of temperature and precipitation. Cyanobacteria cause atmospheric carbon deposition through photosynthesis and most of this deposited carbon is added to the soil as extracellular metabolites (polysaccharides). Extracellular polysaccharides increase the stability of soils and their resistance to water and wind erosion with connecting soil particles to each other (Mager, 2010).

Chamizo et al., (2012) reported that the presence of cyanobacteria and lichens have increased the stability of the soil surface in the desert areas of Spain.

The 4th recommending ammendment is zeolite, as of the most common mineral materials to improve the physical characteristics of soils, especially increases the water storage capacity of soil. Zeolite is an alkaline aluminosilicate which made of a wide three-dimensional network of AlO_4[1] and SiO_4[2] tetragons that are connected each other with sharing the oxygen atoms (Kazemian, 2004), with connected channels and cavities. These spaces are occupied by cations and water molecules, with the ability to move, anion exchange and reversible dehydration (Mumpton, 1999).

The 5th solution is to use red clay to increase the stability of soil particles. Red clay has a good plasticity, it exists near the river and can be used without any special operations. Red clay has a large amount of iron oxides (Wei, 2019), which plays a curtail role in increasing the adhesion of soil particles, especially in light textured soils. Therefore, this study was conducted with the aim of stabilizing loess soils and reducing their erosion by using bentonite, lime, cyanobacteria, zeolite and red clay.

1. Aluminium oxide
2. silicon-oxygen tetrahedron

2. Materials and Methods

2.1. Description of the study area

A loess is a silt-sized sediment that is formed by the accumulation of wind-blown dust.[1] Ten percent of Earth's land area is covered by loesses or similar deposits (Khormali and Kehl, 2011).

The loess soils of Golestan province are located in the geographical region among the Gonbad-Dashli-Brun from the east to Kalaleh-Maraveh-Tepeh from the west, the Kope-dagh Mountains in the north and Gorganrud in the south. These soils are attributed to the early Pleistocene period that identified for the first time in the north part of Iran by Khormali and Kehl, (2011).

2.2. Soil sampling and analysis

Loess soil was sampled from Maraveh-Tepeh of Golestan province with a latitude of 37° 28” N and a longitude of 54°42” E. In the laboratory, a metal box with dimensions of 300 x 75 x 75 cm was used to produce artificial runoff (Figure 1). The box part of this flume was filled with treated soils in specified percentages and then it was placed against the artificial runoff produced by this device with certain and constant intensities for all treatments. Also, we had six treatments (bentonite, lime, zeolite and red clay, cyanobacteria and control) that mixed with loess soil to evaluate the soil resistance to erosion specially water erosion. In all stages of this experiment, the slope of the flume was 30 degrees and the flow of water entering the device was 5 liters per minute.

2.3. Treatments:

- Bentonite, lime and zeolite each with 10% content and red clay with 20% content was mixed with loess.
- Cyanobacteria (*Nostoc* sp.) was collected from Inche Barun region of Golestan province (Figure 1) and placed on soil surface inside the box and after three weeks (100 g was of the samples used per square meter). The content of sediment and soil resistance were measured under these biological and mineral treatments.

2.4. Control with no treatment

In each experiment, samples were taken from the runoff containing sediment at specific time intervals using a stopwatch and collection containers. The duration of each experiment varied between 30 and 120 minutes, depending on the time required to reach the steady state. Runoff samples containing sediment were collected in specific containers and weighed after drying for comparison and statistical analysis.

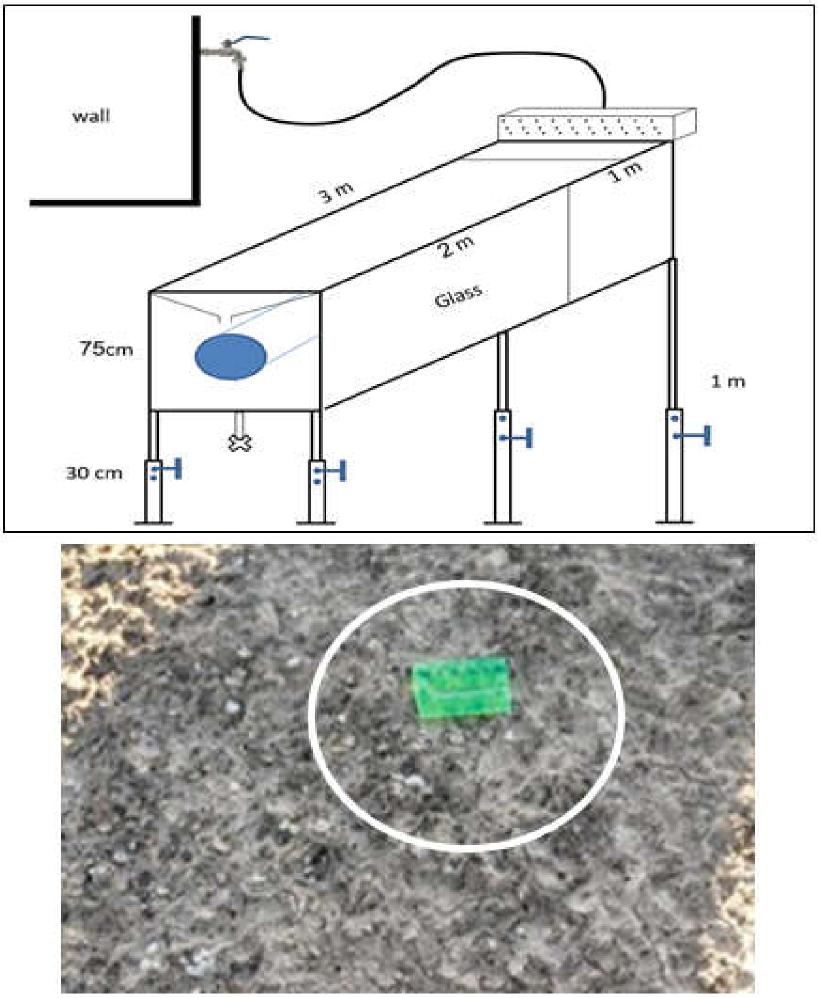

Figure. 1. Laboratory flume and the cyanobacteria applied to the soil.

2.5. pH and EC

The pH of the soil was determined using a digital pH meter (model PH700 Benchtop pH Meter). Soil EC was determined for an aqueous extract of soil using an EC meter (Hanna Instruments, Model HI5321-02).

2.6. CEC, Na (exchange), OC and SAR

Cation exchange capacity (CEC) was calculated by Bower's method (Rhoados, 1982), Organic carbon (OC) by Walkley and Black's method (Nelson and Sommers, 1982), Exchangeable sodium by Acetate-ammonium (one normal at pH=7) (Lavkulich, 1981) and sodium absorption ratio (SAR) of soil was also calculated using the following formula:

$$SAR = \frac{\text{Exchangable sodium}}{\sqrt{\frac{Ca + Mg}{2}}} \quad [1]$$

2.7. Bulk density

Bulk density was found with (Methyl Ethyl Ketone) solution method (Stewart et al., 2012).

2.8. Soil mean-weight diameter

The stability of soil grains was determined using the soil mean-weight diameter of soil grains (MWD) method (Franzluebbers, 2022).

2.9. Soil geometric mean diameter

Soil geometric mean diameter of soil grains was determined using the Francisco et al., (2021) method.

2.10. Soil texture

The soil texture was determined by the hydrometric method after the oxidation of organic matter with hot H_2O_2[3] (Gangwar and Baskar, 2019).

3. Hydrogen peroxide

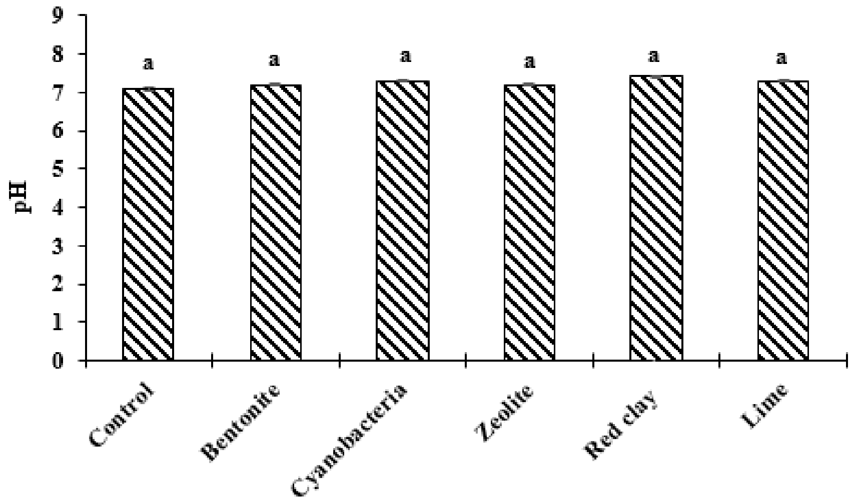

Figure. 2. Effect of study treatments on soil pH Columns tapped with, similar letters are not significantly different ($p<0.05$).

Table 1. Physical and chemical characteristics of the studied soil

Parameter	Unit	Amount
EC*	dSm^{-1}	4.1
pH*	-	7.1
Na (exchange)	($meq100g^{-1}$ soil)	26.4
SAR*	(meq/L)	20.87
CEC*	(cmol $(^{+})kg^{-1}$)	10.52
OC*	(gkg^{-1} soil)	1.05
Bulk density	(gcm^{-3})	1.39
Soil texture	-	Silty clay
Clay	gkg^{-1}	470
Silt	gkg^{-1}	4750
Sand	gkg^{-1}	550

*EC: Electrical conductivity, * pH: Potential of hydrogen, SAR: Sodium adsorption ratio, CEC: Cation exchange capacity, OC: Organic carbon

2.11. Statistical analysis

Duncan's multiple range test was used for post hoc comparisons. Multiple regression models were employed to establish the relationship between different mineral and biological treatments with soil attributes. Significant differences were reported at $p<0.05$.

3. Result and Discussion

The results related to the physical and chemical attributes of the studied soil are presented in Table 1.

3.1 The effect of study treatments on soil pH

The results of the effect of study treatments (bentonite, lime, zeolite and red clay, cyanobacteria and control) on soil pH values are shown in Figure 2. The pH values are the average of three replicates. According on Figure 2, no significant difference was observed among the pH values under the influence of different mineral and biological treatments at $p<0.05$.

3.2. The effect of study treatments on soil EC Red clay

The soil EC values under the influence of different treatments are shown in Figure 3. Like pH, no significant difference was observed among the soil EC values under the influence of different treatments at $p<0.05$.

3.3. The effect of study treatments on soil mean weight diameter (MWD)

A comparison of the effect of different treatments on soil mean weight diameter is shown in Figure 4. A significant difference at the 5% probability level was observed among MWD values under the influence of mineral (bentonite, lime, zeolite and red clay), biological (cyanobacteria) and control treatments. Also, the highest content of MWD was related to lime treatment that has penetrated among soil particles and increased the adhesion of them. However, there was no significant difference between red clay, cyanobacteria and control treatments.

3.4. The effect of study treatments on soil geometric mean diameter (GMD)

Like mean weight diameter, the highest content of GMD of soil was observed in the soil mixed with lime treatment (Figure 5). Also, there was a significant difference among the GMD values under lime, zeolite, bentonite and cyanobacteria treatments at $p<0.05$. However, no significant difference was observed between clay and control treatments.

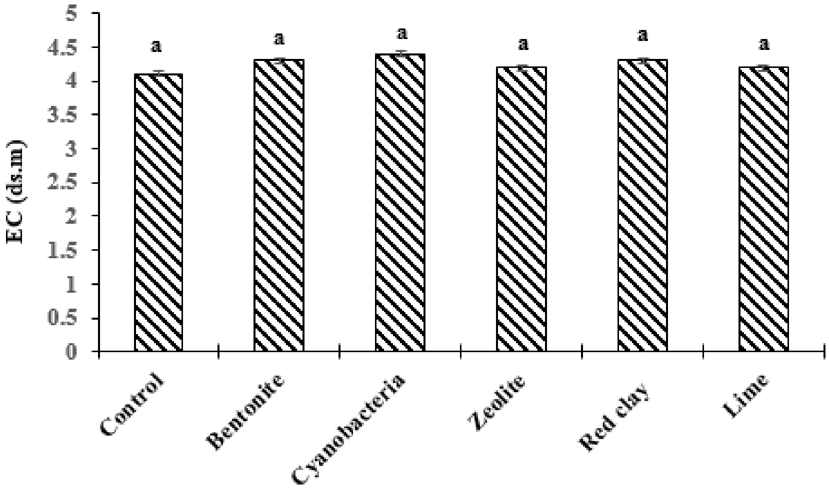

Figure. 3. Effect of study treatments on soil electrical conductivity (EC), Columns tapped with similar letters are not significantly different (p<0.05).

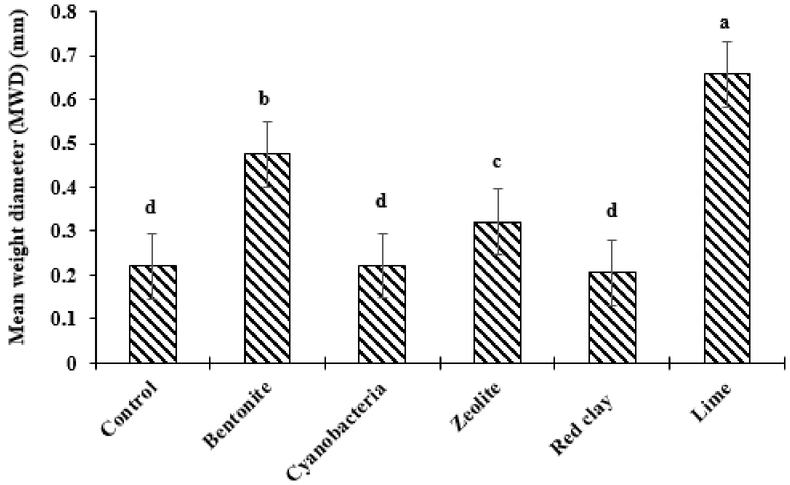

Figure. 4. Effect of study treatments on soil MWD. Soils tapped with different letters indicate significant differences (p<0.05).

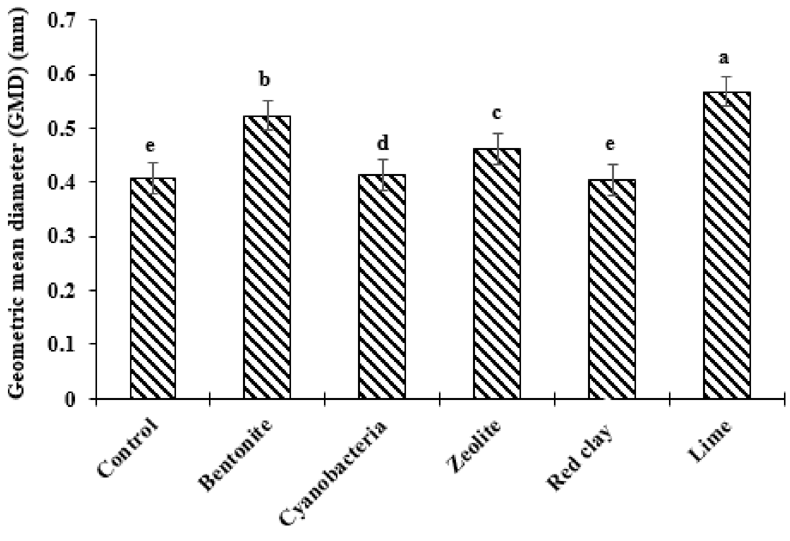

Figure. 5. Effect of study treatments on soil GMD. Bars tapped with different letters indicate significant differences (p<0.05).

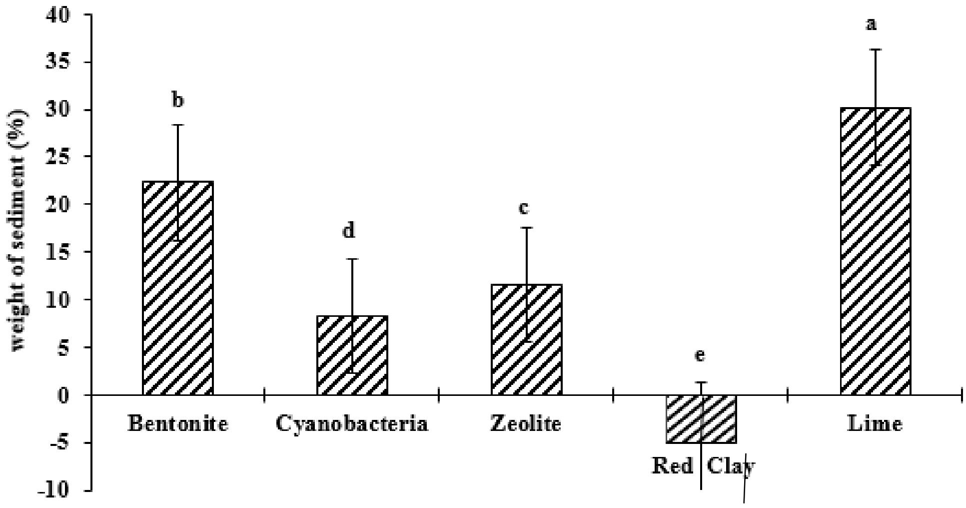

Figure. 6. Effect of study treatments on weight of sediments collected from the runoff. Bars tapped with different letters indicate significant differences (p<0.05).

3.5. The effect of study treatments on weight of sediment resulting from runoff

The effect of study treatments on weight of sediments collected from runoff is shown in Figure 6. Like other measured parameters, the lime treatment had the greatest effect in reducing the content of sediment from the runoff with a 30% reduction compared to the control treatment. Bentonite, cyanobacteria and zeolite decreased the content of sediment from runoff by 20, 8, 10 and 15, respectively. Also, the treatment of red clay by infiltrating the fine pores of the soil causes them to be blocked and by reducing the content of water infiltration, it has increased the sedimentation by 4 percent (Figure 6).

The results showed that lime treatment had the greatest effect on two parameters of soil include MWD and GMD compared to other treatments. Also, the cyanobacteria had no significant effect on the soil MWD compared to control treatment. On the other hand, lime treatment with three times increase, had the greatest effect on soil MWD. After that, bentonite and zeolite increased the mean weight diameter of soil by 2.1 and 1.5 times, respectively, compared to the control treatment. Red clay like cyanobacteria had no significant effect on the MWD of soil. In past studies, the polysaccharide produced by cyanobacteria has caused the adhesion of soil particles and increased the resistance of soil grains as well as increased the MWD content of soils, which was in contrast with the results of this research. It seems that the method of sampling and the use of cyanobacteria treatment is the main reason for this difference. In research of Makubela et al., (2012), the native and selected strain of cyanobacteria was transferred as a solution on soil surface and physical properties analyzed from a depth of 5 mm - which has the most contact with runoff.

Lime can increase the stability of soil in different ways. For example, lime reduces the air pressure in soil by the absorption and capillarity and also increases the swelling of soil as well as the mobility of exchangeable ions in soil (Khazaei et al., 2008). Also, lime acts as a bridge among soil components and increases the stability of soil grains (Khazaei et al., 2008).

Saedi et al., (2016) with investigating the effect of organic matter, clay, silt and lime content on water erosion in different slops showed that the lime treatment increased soil MWD.

Zeolite and bentonite are 2 to 1 clays that have a large interlayer space and ability to absorb a lot of water in their interlayer spaces. With increasing the amount of clay in soil, the water holding power in soil increases and the soil grains become more stable. Feizi et al., (2019) reported that bentonite improves the stability and formation of soil grains. Also, Amirahmadi et al., (2022) reported that the use of zeolite in the application rate of 5 grams per kilogram of soil increased the MWD of soil and soil stability to the runoff. Although the large amount of zeolite in the soil due to the coarse size of its components causes the destruction of structure, dispersion of particles and increases the water waste, which is probably the bentonite has been able to perform better than the zeolite treatment in the stability of soil (Amirahmadi et al., 2022).

Red clay has a very soft texture and it is easily dispersed in water. Also, by penetrating through the soil particles, it prevented the adhesion of them or by closing the pores, it increased the runoff. Therefore, the MWD and GMD of soil was the lowest, but it was not significantly different with the control treatment. Also, the results showed that the significant difference between the treatment of cyanobacteria and red clay was only in the GMD of soil

The cyanobacteria that has settled on the soil surface, prevented the direct contact of water with soil particles and reduced the sediment of runoff which was consistent with the results of Jafarpour et al. 2022. However, the time of establishment of cyanobacteria was not enough to cover the entire soil surface and it has not been able to show the maximum efficiency as other treatments.

4. Conclusion

According to the results, lime treatment was the most efficient treatment in erosion control. After lime, bentonite was the most effective treatment to control water erosion. Also, the results showed that bentonite was almost two times more effective than the zeolite in controlling water erosion. In the red clay treatment, the percentage of sediment reduction compared to the control treatment was negative so that cannot be used to compare with other treatments. However, the red clay had the least effect on erosion control and, as mentioned, increased the sediments produced by the runoff. On the other hand, due to the chemical reaction with water, lime is placed between the soil particles and reacts with them therefore, causes the soil particles connected to each other strongly. Also, this material is cheap and can be used in large scale to prevent soil erosion. Therefore, lime was the most effective treatment in this study.

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References

Ajayi, Emmanuel Sunday. (2012). Effect of Lime Variation on the Moisture Content and Dry Density of Lateritic Soil. In Ilorin, Nigeria. Shabestar, Iran, International Journal of Forest, Soil and Erosion (IJFSE), 2 (4): 165-168. ISSN 2251-6387 [PRINT] 2251-824X.

Akbari Gorgani SM. (2013). Investigating the improvement of the channels placed with lime by conducting pedometer test and numerical modeling (case study of Gorgan loess soil). The third national seminar on geotechnical problems of irrigation and drainage networks. Karaj, Iran. 1-7pp.

Amirahmadi, E., Ghorbani, M. and Moudrý, J. (2022) Effects of Zeolite on Aggregation, Nutrient Availability, and Growth Characteristics of Corn (Zea Mays L.) in Cadmium-Contaminated Soils. Water Air and Soil Pollution 233(436):1-12, http://dx.doi.org/10.1007/s11270-022-05910-4.

Chamizo, S., Cantón, Y., Miralles, I. Domingo, F. (2012). Biological soil crust development affects physicochemical characteristics of soil surface in semiarid ecosystems. Soil Biology and Biochemistry 49:96–105, http://dx.doi.org/10.1016/j.soilbio.2012.02.017.

Dejong, J. T., Mortensen, B. M., Martinez, B. C., and Nelson, D. C. (2010) Bio-mediated soil improvement. Ecological Engineering 36: 197-210. https://doi.org/10.1016/j.ecoleng.2008.12.029.

Feizi, Z., Ayoubi, S., Mosaddeghi, M. R., Besalatpour, A. A., Zeraatpisheh, M. and Rodrigo-Comino, J. (2019) A wind tunnel experiment to investigate the effect of polyvinyl acetate, biochar, and bentonite on wind erosion control. Archives of Agronomy and Soil Science, 65: 1049-1062. http://dx.doi.org/10.1080/03650340.2018.1548765.

Francisco CAL, Loss A, Brunetto G, Gonzatto R, Giacomini SJ, Aita C, Piccolo MC, Marchezan C, Scopel G, Vidal RF. (2021) Aggregation, carbon, nitrogen, and natural abundance of C and N in soils under notillage system fertilized with injection and surface application of pig slurry for five years, Carbon Management, 12:(3) 275-287, https://doi.org/10.1080/17583004.2021.1920822.

Franzluebbers AJ. (2022) Soil-test biological activity associates with soil aggregation characteristics under different land uses in North Carolina, Soil Science Society of America Journal, 86: 1639-165. https://doi.org/10.1002/saj2.20474.

Farooq, S M, M A Rouf, S M A Hoque, and S M A Ashad. (2011) Effect of Lime and Curing Period on Unconfined Compressive Strength of Gazipur Soil, 4th Annual Paper Meet and 1st Civil Engineering Congress, Bangladesh: 4–8.

Frechen M. (2011) Loess in Europe: Guest Editorial. E&G Quaternary Science Journal. 60 (1): 3–5. http://dx.doi.org/10.3285/eg.60.1.00.

.Gangwar DP and Baskar M. (2019) Texture Determination of Soil by Hydrometer Method for Forensic Purpose. Central Forensic Science Laboratory Chandigarh, 1-7pp.

Gueddouda M. K., Goual I., Lamara M., Aboubaker N. (2008). Hydraulic conductivity and shear strength of compacted dune sand-bentonite mixtures, International Conference on Construction and Building Technology, 12 -139-150. https://scholar.google.com/scholar.

Houston S. L., Houston W., Zapata C. E., Lawrence, CH. (2001). Geotechnical Engineering Practice for collapsible soils, Geotechnical and Geological Engineering, 19: 333-355.

Iranian National Committee for Large Dams, geotechnical design of collapsing soils and its importance in terms of dam foundations. (2014) Technical Committee for Dam Foundations, Publication No. 24.

Jafarpoor, A., Sadeghi, S. H., Darki, B. Z. and Homaee, M. (2022) Changes in morphologic, hydraulic, and hydrodynamic properties of rill erosion due to surface inoculation of endemic soil cyanobacteria. Catena, 208: 105782. http://dx.doi.org/10.1016/j.catena.2021.105782.

Kazemian H. (2004) Introduction to zeolites: The magic minerals, Behesht Publications, Tehran, Iran, 130p. https://scholar.google.com/scholar.

Khazaei, A., Mosaddeghi, M. and Mahboubi, A. (2008) Impacts of test conditions, soil organic matter, clay and calcium carbonate contents on mean weight diameter and tensile strength of aggregates of some hamedan soils. Journal of Water and Soil Science, 12: 123-134. http://dorl.net/dor/20.1001.1.24763594.1387.12.44.10.5.

Khormali. F., Kehl M. (2011) Micromorphology and development of loess derived surface and buried soils along a precipitation gradient in Northern Iran, Quaternary International, 123- 234: 109. https://doi.org/10.1016/j.quaint.2010.10.022.

Lavkulich, L.M. 1981. Methods Manual, Pedology Laboratory. Department of Soil Science, niversity of British Columbia, Vancouver, British Columbia, Canada.

Mager, D.M. (2010) Carbohydrates in cyanobacterial soil crusts as a source of carbon in the southwest Kalahari, Botswana. Soil Biolology and Biochemistry 42: 313-318. http://dx.doi.org/10.1016/j.soilbio.2009.11.009.

Maqubela, M. P., Muchaonyerwa, P. and Mnkeni, P. N. (2012) Inoculation effects of two South African cyanobacteria strains on aggregate stability of a silt loam soil. African Journal of Biotechnology: 11, 10726-10735. https://doi.org/10.5897/AJB11.2111.

Management and Planning Organization of Iran. (2003) Instructions for Embankment Stabilization and Road Paving, No. 218.

Mishra U, Lal R, Liu D, Meirvenne MV (2010) Predicting the Spatial Variation of the Soil Organic Carbon Pool at a Regional Scale, Soil Science Society of America Journal, 74: Issue3, 906-914pp. https://doi.org/10.2136/sssaj2009.0158.

Mumpton, F. (1999) Laroca magica: Uses of natural zeolites in agriculture and industry proceedings of the National Academy of Sciences of the United States of America. 96: 3463-3470. http://dx.doi.org/10.1073/pnas.96.7.3463.

Nelson, R.E. and L.E. Sommers. 1982. Total carbon. Organic carbon and organic matter. PP: 539-579. In: A. L. Page et al. (Ed.), Methods of Soil Analysis. Part2, 2nd. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Pawlak S. L. (1998) Evaluation, design and mitigation, collapsible soil sites in Western Colorado, Colorado Geological Survey, Geologic Hazards and Engineering Practices in Western Colorado, Glenwood Springs, Colorado.

Rhoados, J.D. 1982. Cation exchange capacity. PP: 149-158. In: A. L. Page et al. (Ed.), Methods of Soil Analysis. Part 2. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Saedi, T., Shorafa, M., Gorji, M. and Moghadam, B. K. (2016) Indirect and direct effects of soil properties on soil splash erosion rate in calcareous soils of the central Zagross, Iran: A laboratory study. Geoderma, 271: 1-9. http://dx.doi.org/10.1016/j.geoderma.2016.02.008.

Umer MI, Rajab SM, Hajeen Ismail K. (2020) Effect of CaCO3 Form on Soil Inherent Quality Properties of Calcareous Soils, Materials Science Forum 1002:459-467, http://dx.doi.org/10.4028/www.scientific.net/MSF.1002.459.

Vasiljevic, D. A.; Markovic, S. B.; Hose, T. A.; Smalley, I.; O'Hara-Dhand, K.; Basarin, B.; Lukic, T.; Vujicic, M. D. (2011) Loess towards (Geo) Tourism – Proposed Application on Loess in Vojvodina Region (North Serbia), Acta Geographica Slovenica (in Slovenian). 51 (2): 390–406. https://doi.org/10.3986/AGS51305.

Wei, F. 2019. Regional Stability Analysis of Red Clay Slope Based on Different Failure Modes: A Case Study in Taizaifu Area, Fukuoka, Advances in Civil Engineering: 1269832, 11 pp, https://doi.org/10.1155/2019/1269832.