Improvement stability of earth canal banks using geo-technical approaches

S. A. Hosseini and F. Sharifi

ABSTRACT
Splash erosion is one of the common erosional features, which is happening in the steep slope of sidewall of earth structures. Accordingly, it is necessary to use erosion control procedures in some sections of the route, especially in the intersection with other structures or in the intervals of channel route in the vicinity of access road or agricultural lands. Application of bio-mulches and well-known natural modifying agents are being used to control erosion. This research aimed to control splash and rill erosion processes along the steep slope of sidewall of earth structures and to find out the best modifying agents and bio-mulches to enhanced stability of soil profile. The research method was formulated to use experimental methods to simulate rainfall in different intensities and durations using rain simulation laboratory of soil protection and watershed management research institute. In addition, modifying agents and bio-mulches were applied in order to discover optimum compounds to improve stability of soil resistance parameters on the sidewalls of irrigation and drainage channels. Further, geometry of the irrigation and drainage channels (Khuzestan Province, Southwestern of Iran) was used to setup experimental procedures. In total, 290 tests were conducted using 15 types of modifiers and bio mulches. The resultant data have emphasized on effectiveness treatments using bio-mulches and groups of cements such as sulfate, slurry and lime, and soil mixture with a confidence level of 95 percent. For instance, bio-mulches were increased soil resistance upon to 89% rate of erosion along the sidewalls of drainage channels. Sulfate resistant cement slurry treatment has represented the best performance among other soil-modifying agents with a rate of 98%. The present research has introduced applicability methods of the bio-mulch and soil-modifying agents in soil erosion control.

1. Introduction

The mechanical properties of most soils alter upon increase of moisture and saturation. In some soils, certain phenomena appear due to increased moisture. Some of these phenomena lead to major damages in development projects. These soils are called “Sensitive soils to water.” The most significant types of these soils include swelled soils, dispersive soils, and collapsible. Dispersive soils refer to clay soils that are easily washed up in waters of low concentration of salt. Dispersion is a progressive phenomenon that starts from one point and is gradually extended. The start point of the dispersive phenomenon may refer to cracks resulting from shrinkage, soil deposition or cracks made due to roots of plants. This phenomenon is of great importance in such plans as soil dams and water supply channels where there is a water concentration inside the soil too. Thus, some problems rise in the wall of the soil channels that cannot be repaired. Improvement of quality and alteration of dispersive soils is usually possible by using such additives as gypsum, lime, etc. The additive decreases sodium ions that are present in soil and replaces the same with calcium ions and eventually decreases the dispersive property of soil. The most common type of these materials is lime.

Using covering products is among the most appropriate management measures for temporary soil stabilization that are used to protect the slope of hills (Fathi-Moghadam, 2006). The role of these products has been confirmed in decrease of erosion of walls of expressways, forest roads, railways embankments, and places that are under construction (Gholami, Sadeghi, & Homae, 2012). Nowadays, extensive use of mulches such as straws on slopes on the margin of highways has motivated many researches to develop the systems that are of more simple usage and resistant against erosion (Kurien, Praveena, Rehna, & Shijila, 2014).

The effect of various variables such as type of fibers, weight percentage, and length of fibers on improvement of shear behavior of reinforced sand soil with natural fibers, namely straws and hemp by using direct shear test, has studied and measured. The
distinguished result in these tests was increased shear resistance of sand mixture with random distribution of fibers within a span of moisture of 14%. However, upon increase of moisture, shear behavior of the reinforced soil is quite different. Increasing length of fibers up to 20 m led an increase in the shear resistance if the percentage of fibers was constant, while increasing length over 20 mm led to a decrease of resistance accordingly (Okhovat, Pourhosseini, Abtahi, & Hejazi, 2011). The effect of ash of wastewater ooze on increasing pressure resistance of clay soil under laboratory condition in two states of optimized and satirized moisture studied. After processing four types of treatments, different unenclosed pressure resistance tests have been done on the said treatments. The results have revealed that upon increase of ash of ooze to soil, unit weight of dry volume is decreased and optimized moisture is increased, respectively. Moreover, increase of ooze ash to soil increases the pressure resistance in both conditions of optimized and saturated moisture (Norouzian, Abbasi, & Abedi Koupai, 2015). The effect of ash of rice husk and lime on technical characteristics of clay soils studied. Considering the said research, when lime of 12% and ash of rice husk of 12.5 were added to soil, plasticity index (PI) of the sample was decreased from 41.25% to 0.96% and swelling potential from 19.23% to 0.019%, respectively. Moreover, this research revealed that in case lime of 6% and ash of rice husk of 12.5 are used, internal friction angle and adhesiveness of the sample will be increased from 5.36% to 23.85% and 54.32 KN/m² to 157.19 KN/m², respectively. This increase in the shear parameters of the sample leads an increase in the loading capacity of soil from 391/12 KN/m² to 4131 KN/m² as well (Defersha, Quraishi, & Melesse, 2011).

Acosta, Hedil, and Benson (2003) reported the effect of wind ash with increasing the pressure resistance. The results revealed that increasing processing time leads to an increase in the pressure resistance.

This research aims to study the role of bio-mulches, improvers, and altering materials in decrease of erosion and sedimentation of side walls of channels in irrigation and drainage network of Arayez Plain of Khuzestan province in Iran. The methods of stabilizing the wall of these soil canals, which contain a significant percentage of deactivated lime, are considered to be a novel and applied technique.

2. Materials and method

This research has been conducted on a soil with a loam sandy texture of irrigation and drainage channels network of Arayez Plain of Khuzestan province in Iran. The annual rainfall in this area is 255 mm and the evaporation rate is 2100 mm. This place is located on the west side of Karkheh River on the latitude of 31°,45' to 32°,25' and longitude of 47°, 50' to 48°, 30' on the east side. A two-nozzle precipitation of K18 feature was performed using a simulated system. Figure 1 shows a schematic view of the situation of Karkheh and area subject of this research in the nation.

In order to determine the effect of mulches and different correcting materials on parameters of side wall erosive resistance of the soil structure, after soil of the region passes through a sieve of 4.75 mm was put in the basin designed for 1 m × 0.33 m x 0.1 m for about 25 kg. After filtration, leveling and pressing the soil to the side of Flume basin proportionate to the physical special weigh of soil, the stabilizing materials and different bio-mulches were sprayed in different concentrations. Then, the basins inside the Flume with a side slope of 80% were put into the depth of 10 cm. Figure 2 shows the preparation of treatments, Torvane Device, and measurement of primary moisture shown by using TDR device. The tests related to determining the uniformity of precipitation and setup of different intensities of precipitation has been conducted by applying the required changes in the electronic control device and the electrical valve connected to the nozzles.

In each experiment, without any covers soil (control treatment) and soil impregnated with 15 different covers were exposed to two precipitation intensities of 30 and 80 mm/h (maximum rainfall intensity in the region with a return period of 100 years). The duration of each experiment was 30 minutes, because during this time the amount of sediment concentration in the runoff was in equilibrium. In balance or sustainable condition, changes of sediments discharged from the outlet of Flume are fixed in proportion to time. The rest of each treatment was repeated for three times. The penetration of water to soil was collected by a rubber tube devised on the floor of the metal basin.

In order to determine the weight of dry sediment of each runoff, the entire mixture of the runoff and sediment gathered in the rubber buckles were used. Thus, first the sediments deposited in the special basin were exposed to heat of 105°C for 24 h by an oven. After drying and reweighing, the weight of dry sediment was calculated. Figure 3 shows a schematic view of the arrangement and collection basin of runoff, sediment and penetration of flow to treatments, manner of measurement of shear resistance by using Torvane device and calculation of secondary moisture of soil by using an oven.
Figure 1. A schematic view of the situation of Kharkheh region and the area subject in Iran.

Figure 2. Preparation of treatments (a), Torvane Device (b), and measurement of primary moisture of treatments by using TDR device (c, d).
3. Results

Study of the simulated precipitations in soil without covering (Control treatment):

In each series of simulated tests on the control treatment, sediment, runoff, water penetration, soil moisture before and after test and shear resistance of soil subject of test at the side slope of 80% with precipitation intensities of 30 and 80 mL per hour were measured. These series of tests were repeated for control treatment for four times. The average quantities resulting from these tests were used as final result. Table 1 shows the quantities obtained from test in sample soil without covering (control treatment) in two intensities of precipitation.

Investigation of precipitation on soil characteristics stained with mulches and different correcting materials

The effect of simulated precipitations on the soil stained with four types of mulches and 11 correcting materials on sediment, intensity of runoff and water penetration in soil and other parameters in slope of 80% with an intensity of precipitations of 30 and 80 ml per hour were separately studied. It should be mentioned that any of mulches and correcting materials were tested in three intensities or concentrations of the minimum, average and maximum. The densities used were chosen based on cost and economic standards of each treatment aiming at stabilizing the soil of side wall of the channel.

3.1. The effect of precipitation on sedimentation of different materials used

Spray of mulch and correcting materials on the soil ground subject of research was made by using a spray. After spraying of mulch and correcting materials, soil basins were exposed to simulated precipitations at the side slope of 80%. In each test, sedimentation, runoff, penetration, moisture, and shear resistance of soil were measured. The following figures show the relationship between density of bio-mulches and correcting materials used and sedimentation in precipitations of 30 and 80 mL per hour on the sample soil of Arayez Plain of Khuzestan.

Table 1. The results of quantities of sediment, runoff, and water penetration in control soil (without covering) in different simulated intensities.

| Rainfall intensity (mm/h) | Sediment (kg/m²) | Density (g/L) | Runoff rate (mm/h) | Runoff coefficient | Stream power (w/m²) | Influence (mm/h) | Bulk humidity (%) | Shear strength (kg/cm²) |
|--------------------------|-----------------|--------------|--------------------|--------------------|--------------------|------------------|------------------|------------------------|
| 30                       | 0.074           | 12.77        | 11.636             | 0.388              | 2.54               | 1.239            | 32.46            | 0.514                  |
| 80                       | 0.222           | 9.42         | 47.102             | 0.589              | 10.27              | 1.698            | 36.17            | 0.476                  |
Figure 4 shows the effect of precipitation on sediment in control treatment and soil containing kinds of mulches and correcting materials in the minimum density used. Upon increase of precipitation, sedimentation is increased. In two treatments, polypropylene fibers mortar and mixed treatment of fibers mortar and water and lime saturated solution, in both precipitations, the increase of sediment as compared to control treatment is remarkable.

Figure 5 shows the effect of precipitation on sediment in control treatment and soil containing kinds of mulches and correcting materials in minimum density used from each treatment. Upon increase of precipitation, sediment in all treatments is increased.

**Figure 4.** A comparison of the effect of precipitation on sedimentation in control treatment and treatment containing kinds of materials of minimum materials used.

**Figure 5.** A comparison of the effect of precipitation on sediment in control treatment and soil containing kinds of materials of average density used.
at a less rate. Thus, in both treatments of polypropylene fibers mortar and combined treatment of saturated fibers mortar and water and lime saturated solution, increase of sediment compared to the control treatment is noticeable.

Figure 6 shows the effect of precipitation on sediment in control treatment and soil containing kinds of mulches and correcting materials in maximum density used. Upon increase of precipitation, sediment in all treatments is increased at all treatments at a less intensity. However, in both treatments of saturated polypropylene fibers mortar and combined fibers mortar treatment and saturated water and lime solution, the increase of sediment compared to control treatment is noticeable as well. This means that fibers treatment is not the only proper option for control of erosion through side part of the channels.

All mulches compared to control treatment have had a remarkable effect on decrease of sediment. Moreover, it was found that increase of density of mulches used in all densities has had a remarkable effect on decrease of outlet sediment. Furthermore, it was realized that precipitation factor affects the increase of sediment. Thus, this effect in mulch 2 is the least effect in such a manner that upon increased rainfall in mulch 2 m we see the minimum increase in the amount of sediment. The results with respect to other correcting materials are given as follows: anti-sulfate cement and grout treatments with a decrease of 95% and 98% of sediment had the best performance.

Polypropylene fibers mortar treatments of saturated water and lime solution and saturated water and gypsum solution stand in the second and fourth places, respectively, in terms of sedimentation. Thus, all of the said four treatments in more densities tested show higher sedimentation compared to control treatments. Moreover, saturated polypropylene fibers mortar combination treatment and saturated water and lime solution in all densities used and in both intensities of precipitations show the highest sedimentation and they are regarded as the most improper treatment. Thus, compared to control treatment, this treatment has increased sedimentation for about 15 times on average.

On the whole, the results of tests have confirmed that the treatments prepared in form of polypropylene fibers mortar in particular are not effective in control of erosion. Instead, they increase sedimentation. Although it seems that sediment resulting from this treatment is originated from the quantity of primary soil mixed with fibers. The most important advantage of usage of non-saturated polypropylene

Figure 6. A comparison of the effect of precipitation in sediment in control treatment and soil containing kinds of materials in maximum concentration used.
fibers is to increase the soil stability and prevent the earth fall. Thus, this treatment kept its stability for about 3 h of continuous precipitation (for about six times as much as usual time in each test) and did not fall either.

SPSS software was used for statistical analysis of data and ANOVA and Duncan test were used for statistical comparison of data. Considering the tables obtained from data variance analysis and considering the statistic F and significance level, it can be said that all treatments are different in a significance level of 95% with respect to extent of sediment and there is a significant difference in the sediment amount of each of them as compared to test control treatment (Tables 2, 3, 4).

4. Discussion and conclusion

The tests conducted on the soil of drainage channels of Arayez plain with a loamy–sand texture indicated that the presence of mulch coverage results in reduced sediment arising from rainfall in the manner that by the increase of density in any of the mulches, sedimentation reduces accordingly. The results obtained from statistical analysis of this research confirmed that there is a significant difference in a level of 95% between sediment amounts of test control and mulch treatments for the sample of the soil under study. Therefore, biomulches have an effective role in erosion control and decrease of sediment from the walls of soil channels.

Comparison of the results related to two combinational treatments, namely polypropylene-saturated fibers mortar with water and lime saturated solution, and non-saturated polypropylene fibers treatment with water and lime saturated solution through spraying method, showed that preparation procedure of consuming materials by spraying or preparation through mortar process, especially water and lime saturated solution, is very important. According to the results, in the method of spraying the water and lime saturated solution, sediment amounts have decreased about 63% as compared to water and lime saturated solution mortar.

Considering the sharp changes in the amount of outgoing sediment of the treatments under study, in order to display the results of sediment amounts more appropriately, treatments with fewer changes than the test control treatment and treatments with changes sharper than test control treatment are shown in Figures 7 and 8, respectively. As seen in the aforesaid figures, in bio-treatments, mulch 1 had the highest effect in sediment decrease with an amount of about 89%. As for the treatments related to application of soil modifiers, anti-sulfate cement slurry treatment had the best effect in sediment decrease with an amount of about 98%.

In combinational options, polypropylene fibers treatment with mulch 4 had the highest effect in sediment decrease to an amount of 99%.

| Table 2. Results of variance analysis comparing the amounts of sediment in different mulch treatments. |
|---------------------------------------------------------------|
| Source | Type III sum of squares | df | Mean square | F | Sig. |
| Corrected model | 0.213a | 25 | 0.009 | 11.299 | 0.000 |
| Intercept | 0.150 | 1 | 0.150 | 199.178 | 0.000 |
| Intense | 0.069 | 1 | 0.069 | 92.035 | 0.000 |
| Name | 0.103 | 12 | 0.009 | 11.428 | 0.000 |
| Intense * name | 0.040 | 12 | 0.003 | 4.441 | 0.000 |
| Error | 0.039 | 52 | 0.001 | – | – |
| Total | 0.402 | 78 | – | – | – |
| Corrected total | 0.252 | 77 | – | – | – |

| Table 3. Results of variance analysis comparing the amounts of sediment in different mulch treatments of natural modifiers. |
|---------------------------------------------------------------|
| Source | Type III sum of squares | df | Mean square | F | Sig. |
| Corrected model | 140.550a | 37 | 3.799 | 635.376 | 0.000 |
| Intercept | 36.985 | 1 | 36.985 | 6186.299 | 0.000 |
| Intense | 15.634 | 1 | 15.634 | 2614.953 | 0.000 |
| Name | 85.211 | 18 | 4.734 | 791.817 | 0.000 |
| Intense * name | 39.705 | 18 | 2.206 | 368.959 | 0.000 |
| Error | 0.545 | 76 | 0.006 | – | – |
| Total | 177.990 | 114 | – | – | – |
| Corrected total | 141.004 | 113 | – | – | – |

| Table 4. Results of variance analysis comparing the amounts of sediment between different combinational mulch treatments and natural modifiers. |
|---------------------------------------------------------------|
| Source | Type III sum of squares | df | Mean square | F | Sig. |
| Corrected model | 86.737a | 31 | 2.798 | 176.141 | 0.000 |
| Intercept | 20.237 | 1 | 20.237 | 1273.983 | 0.000 |
| Intense | 3.918 | 1 | 3.918 | 246.659 | 0.000 |
| Name | 70.322 | 15 | 4.688 | 295.135 | 0.000 |
| Intense * name | 12.496 | 15 | 0.8330 | 52.446 | 0.000 |
| Error | 1.017 | 64 | 0.160 | – | – |
| Total | 107.990 | 96 | – | – | – |
| Corrected total | 87.753 | 95 | – | – | – |
Figure 7. Percentage of changes in sediment amounts of treatments with fewer changes as compared to test control treatment in different rainfalls.

Figure 8. Percentage of changes in sediment amounts of treatments with drastic changes as compared to test control treatment in different rainfall intensities.
Moreover, results show that application of combinational treatment of polypropylene fibers mortar with water and lime saturated solution will have the most inappropriate function in soil stabilization and erosion control in the lateral walls of channel averagely with 1,500% increase in sediment amount as compared to test control treatment. Increased soil stability and prevention from earth fall are the most important advantages of application of non-saturated polypropylene fibers, in the manner that this treatment kept its stability and did not fall during about 3 h continuous rainfall with maximum intensity (about 6 times the normal time in each test).

Results of some parts of the conducted research conforms to the study conducted by Davoudi, Astaneh, and Alvandkouhi (2009) according to which, by the increase of lime to soil saturation solution in the projects due to any reason in which excavation, modification and restoration will not possible. In his studies, lime solution had been introduced as the main factor in soil mechanical and physical properties. Results of Atterberg limits and direct cut and measurements of chemical parameters of water and soil in the aforesaid study showed that half-percent increase of lime by weight in the soil would increase its adhesion and internal friction angle nearly up to 220% and 300%, respectively, and would decrease its initial settlement and PI up to 14% and 58%, respectively. Moreover, in Forouzesh’s (2012) study in which the effects of polypropylene fibers and fly ash were tested for stabilization of clay and clay-sandy soils, it was specified that addition of polypropylene fibers to clay would slightly decrease uniaxial resistance, but it would increase significantly against soil formation. But as for the samples containing 20% sand in the clay, uniaxial resistance and formation of samples increase by addition of fibers and this conforms to the results of this study.

In the studies conducted by Hashemi Tabatabaei and Aghaei (2008) in which the effect of lime and soil mixture on resistance changes of soil was studied, it was specified that the effects arising from slow movement of water on the soil surface which would result in outbreak of events such as inflation, dissolution, divergence, earth fall as well as changes in additional water pore pressure, by adding lime and other reinforcing materials to fine grained and swelling soils as well as reinforcing materials that experience less erosion in the nature such as cement, lime and micro silica, not only a higher resistance is achieved, but also soil swelling is prevented to a reasonable extent which conforms to the results of this study.

**Highlights**

1. All mulch treatments and treatments of sulfate resistant cement mortar, cement slurry, and lime and soil mixture had a significant effect on sediment decrease in a level of 95%.
2. Application of soil-modifying agents, sulfate resistant cement slurry treatment had the best effect (about 98%) in sediment reduction.
3. Preparation procedure of used treatments through spraying the materials or preparing them through making mortars highly effective on the amount of sediment load.

**Acknowledgments**

This paper is a part of results of the research project which is being conducted by Soil and Watershed Protection Research Institute. This is to appreciate the financial supports provided by Jihad Nasr Institute and supports of Soil and Watershed Protection Research Institute.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

**ORCID**

S. A. Hosseini (http://orcid.org/0000-0002-0235-7017)

**References**

Acosta, H. T., & Benson, C. (2003). Soil stabilization and drying using fly ash. (Geo engineering Rep.No.03-03). Madison: Dept. of civil and environmental engineering, univ.of Wisconsin- Madison.

Davoudi, M. H., Astaneh, F., & Alvandkouhi, H. (2009). Introducing new way to use lime to correct soil characteristics and evaluate it. *Journal of Agricultural Engineering Research, 10*(2), 57–70.

Defersha, M. B., Quraishi, S., & Melesse, A. (2011). The effect of slope steepness and antecedent moisture content on intensities of erosion, runoff and sediment size distribution in the highlands of Ethiopia. *Hydrology and Earth System Sciences, 15*, 2367–2375.

Fathi-Moghadam, M. (2006). Effects of Land slope and flow depth retarding flow in Non-submerge vegetated Land. *Journal of Agronomy, 3*(5), 536–540.

Forouzesh, K., & Gorbani, E. (2012). Improve the mechanical properties of clay and sandy clay using cement and fly ash and fiber-reinforced polypropylene. *The Sixth National Congress of Civil Engineering*. Iran: University of Semnan.

Gholami, L., Sadeghi, S. H., & Homaei, M. (2013). *Straw mulching effect on splash erosion, runoff, and sediment yield from eroded plots*. Soil Science Society of America Journal. [https://www.researchgate.net/publication/251094511](https://www.researchgate.net/publication/251094511)

Hashemi Tabatabaei, C., & Aghaei, A. (2008). *Compare alive lime and flourish on soil geotechnical properties*. Tehran, Iran: Construction and housing research center.

Kurien, E. K., Praveena, K. K., Rehna, M., & Shijila, E. (2014). *Soil erosion studies on micro plots*. *International Journal of Engineering Research and Development, 9*(7), 15–19 15. [http://www.ijerd.com/](http://www.ijerd.com/)
Norouzian, K., Abbasi, N., & Abedi Koupai, C. (2015). The use of sewage sludge ash to improve the engineering properties of clay soils on offshore structures. *Journal of Agricultural Engineering, 5*(4), 93–108. Iran.

Okhovat, N., Pourhosseini, R., Abtahi, S. M., & Hejazi, C. M. (2011). Improvement of the soil, using natural fibers. *Fifth National Congress on Civil Engineering*. Iran: Ferdowsi University of Mashhad.