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Dynamic behavior of Vetiver roots for slope bioengineering in temperate and cold mountainous regions

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Abstract

Soil is one of the most important natural resources. Soil conservation and erosion reduction in different regions are at the forefront of economic empowerment. Vetiver (Chrysopogon zizanioides) cultivation is known as one of the most effective bioengineering solutions for stabilizing steep slopes. This effect was investigated in this study with the aim of investigating the capacity of Vetiver plants to be exposed to combined stress factors. This study represents the first experimental application of Vetiver (Chrysopogon zizanioides) for slope stabilization in temperate and cold mountainous regions of the world. This study was conducted on the lateral slopes of the Narmab Dam reservoir located in Minoodasht County, Golestan Province. In this study, soil and Vetiver root sampling was carried out from a depth of 0–50 cm along the dam reservoir wall with different degrees of slope: first level (60–70 degrees), second level (70–80 degrees), third level (80–90 degrees) with three replications. Root characteristics, including biomass weight, diameter, and root area ratio (RAR), were used in this study. These root extract profiles were extracted from dried roots using a methanol/water (80/20) solution by soaking and concentrated by rotary evaporation. The data were analyzed using analysis of variance and comparison of means (SPSS). The findings highlighted the significant effects of slope location and presence of Vetiver on soil stability, root biomass and root extract yield. The study showed that slope location and presence of Vetiver plants had significant effects on soil stability. The biomass and root diameter gradually increased up to a depth of 20 cm, with Vetiver roots increasing soil cohesion by %199, with the deepest level showing significantly higher values ($p < 0.05$). The results confirmed that Vetiver significantly improved soil shear strength at different slopes (60–70°, 70–80° and > 80°), with an increase ranging from 27.327% to 78.13%. The increase in root biomass, diameter and extract yield indicates the adaptive response of the plant to environmental stresses. Planting Vetiver plants on steep slopes is recommended due to their high adaptability to different climates and conditions, their smart performance and the possibility of growing early seedlings.

Keywords: Shear stress, Root weight, Root extract, Erosion

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1 Introduction

The intensification of soil erosion and degradation is caused by the complex interaction of climatic factors, topography, vegetation cover, and land management practices. Therefore, effective erosion control and soil quality maintenance are essential to ensure agricultural and environmental sustainability Nosrati et al. [1]. There is a direct relationship between improving vegetation cover and improving soil properties and ultimately reducing soil erosion Khaleghi [2]. Today, the method of using plants has received more attention due to its cost-effectiveness and positive environmental impact. In this method, soil resistance and stability are maintained with the help of planting vegetation on sloping lands and slopes Sharifi [3]. Vegetation can contribute to slope stability with both mechanical and hydrological effects Mohsenipour et al. [4]. The role of appropriate vegetation in managing and reducing runoff and sediment is very important and effective Asgari et al. [5]. Plants increase slope stability by drying the soil through transpiration and mechanically reinforcing the roots. The method of maintaining soil strength and stability is carried out with the help of planting vegetation on steep slopes. Landslides caused by shallow rains, especially in mountainous areas, have increased public awareness of this risk. Therefore, slope instability is a major concern and combined technical and biological measures are particularly suitable for slope protection Noor et al. [6]. Vetiver combines environmental compatibility with cost-effectiveness and durability Haghighi and Sharifi [7]. Vetiver cultivation is a very cheap and highly resistant method of soil protection Ghanbari et al. [28]. When the soil surface is covered with Vetiver vegetation, soil loss is also significantly reduced Asgari et al. [8]. The Vetiver root system reduces runoff and increases the moisture available to the plant, and also prevents soil movement from the upper part of the slope to the lower part of the slope. Different parts of the Vetiver plant have their own medicinal properties Khatuni and Kolahi [9]. Vetiver cultivation is carried out in more than 40 countries around the world for agricultural and non-agricultural purposes. In Iran, some provinces such as Gilan, Golestan and Tehran were cultivated in 2015 with the aim of reducing landslides and soil erosion on steep slopes. This plant increases soil cohesion and shear strength by increasing root diameter Haghighi [10]. The mineral and environmental conditions of the soil in which roots are located are constantly changing. At the morphological level, plants can increase or decrease their growth patterns under suitable conditions Jones et al. [11]. The most important factors affecting the secondary chemical composition of plants are genetic factors, environmental factors and their interaction. One of the most important environmental factors that significantly affects the quantity and quality of plant bioactive compounds includes light, temperature, humidity, as well as the slope and altitude of the planting site. The environmental factor of slope and soil characteristics has a significant impact on the quantity and quality of essential oils and plant extracts Alipour et al. [12]. In fact, the extract or substances secreted by the roots of Vetiver plants in the soil are aimed at strengthening and creating adaptation. In this study, the assessment of the adaptation capacity of Vetiver plants under the influence of biotic stresses such as temperate and cold mountain climate conditions, slope, altitude, as well as abiotic stresses related to soil characteristics has been considered. Since the

side walls of reservoirs, dams and other steep slopes are exposed to landslides and soil movement from the top to the bottom, they need to be stabilized and protected by soil vegetation. Choosing the right plant with high adaptability and its multi-purpose application is very effective in the successful implementation of soil conservation and slope stabilization projects.

2 Methods

2.1 AStudy Area

Sample Part of the border lands of Narmab Dam is in Minodasht, which is located between coordinates 36°25' to 38'8' North and 53°50' to 56°11' East in Golestan province. With a slope above 45%, Minodasht city occupies 4.2% of the area of Golestan province with 700 square kilometers and is located in the east of the province and is 110 kilometers away from the center of the province (Gorgan). The climate of mountainous Minodasht is mild and humid, and the highest and lowest temperatures are reported as 45 degrees above zero and 2 degrees below zero, respectively. The relative humidity of this area is between 41 and 68%. Also, the average annual rainfall is about 450 mm. The mountainous region of this region is more than 3000 m including the high mountains of Alborz slopes with long frosts and cold winters and short and cool summers with the special climate of the highlands. The amount of rainfall in Golestan province in 2014 when Vetiver plant was planted in this area was about 450 mm. This province is one of the northern provinces of Iran, bordering North Khorasan province from the east, Semnan province from the south, Mazandaran from the west, and Turkmenistan from the north (Fig. 1).

2.2 Measurement methods

In this study, Vetiver roots were sampled at three levels with different degrees of slope from a lateral slope in Tehran province, with the aim of determining the relationship between soil properties and the results of direct measurements of soil shear stress with the weight of roots and the weight of extract extracted from Vetiver roots. Vetiver plants were cultivated on the slopes of Tehran province with an area of (20×70 m^2) at three levels (terraces) with the aim of reducing landslides and soil subsidence. In this study, with the aim of evaluating the adaptability of Vetiver plants under the influence of biotic and abiotic factors (soil shear stress), soil and Vetiver root sampling was carried out from a depth of 0–50 cm with different degrees of slope (first level 60–70 degrees, second level 70–80 degrees, third level 80–90 degrees) and at each level with three replications (total number of soil samples 9 and total number of Vetiver root samples 9). Soil properties including soil grain size analysis by hydrometric method, physical and chemical properties of soil were measured according to standard laboratory protocols. Soil moisture was determined by gravimetric method Jafari Haghighi [29], pH was measured using saturated paste method and electrical conductivity (EC) was obtained from saturated soil extract. Organic matter percentage and lime content were also analyzed

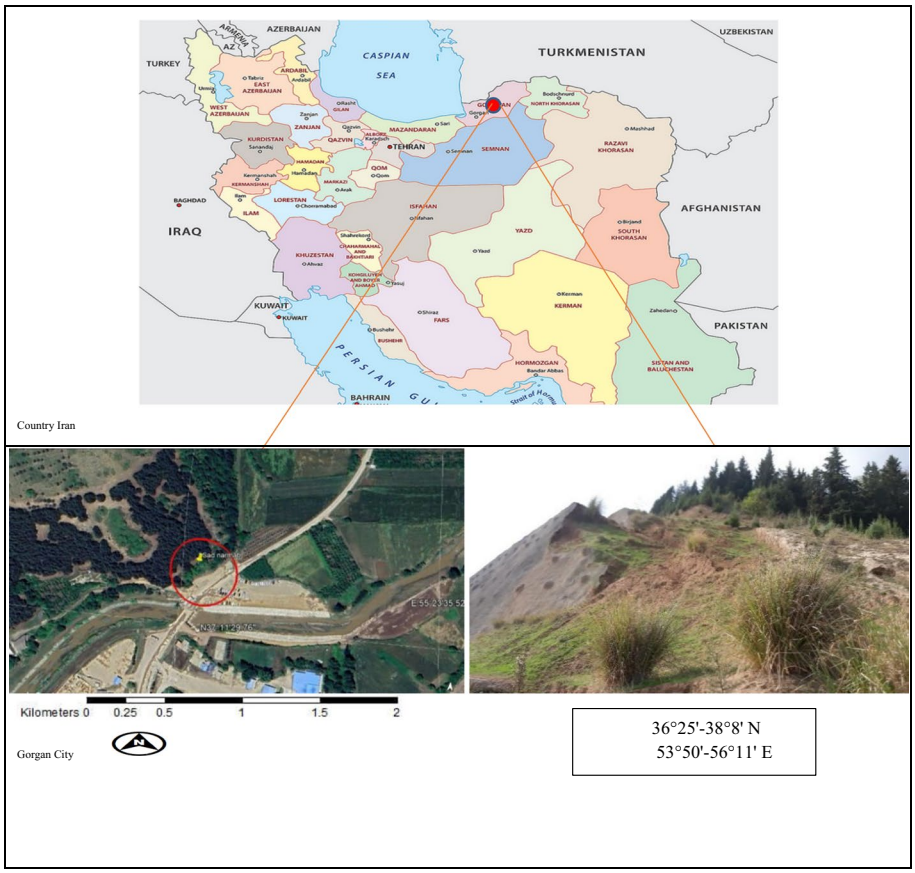


Fig. 1 Location of study area

according to the same reference. Potassium concentration was determined using flame photometry Jafari Haghighi [29]. The first step was to measure the soil shear stress in the vicinity of the Vetiver roots, the initial soil moisture was recorded at the sampling site. Soil sampling was carried out separately without Vetiver roots and also with Vetiver roots using a 20 cm high steel cylindrical container. Sampling was carried out at four depths (0–5 cm, 5–10 cm, 10–15 cm and 15–20 cm). The samples were then sent to the soil mechanics laboratory for further testing. Using a hydraulic jack, the mold was filled with undisturbed soil and the sample mold was placed in the direct shear test machine using ceramic and metal sheets. As the soil depth increased in the mold samples that were separated from the steel ring container for shear stress measurement, the force and weight applied to the molds in this manner (kPa 0 kPa, 20 kPa, 40 and 60 kPa) increased accordingly for the first mold from the soil surface (0–5 cm), the second mold depth (5–10 cm), the third mold from the depth (10–15 cm) and the fourth mold from the depth (15–20 cm) in the direct shear test soil measurement machine (Fig. 2), Direct shear tests were performed on intact and recompacted specimens, the geometry of the specimens was square and the direction of the roots relative to the shear plane was simulated by crossing the intact root networks, the shear displacement rate was less than 0.1/min and no drainage was performed. To describe the root density, i.e. the abundance of roots in the soil, a parameter called RAR (Root Area Ratio) is used (Fig. 3), where



Fig. 2 Soil shear stress measurement—Water and Soil Chemistry Laboratory, Soil Conservation and Watershed Research Institut

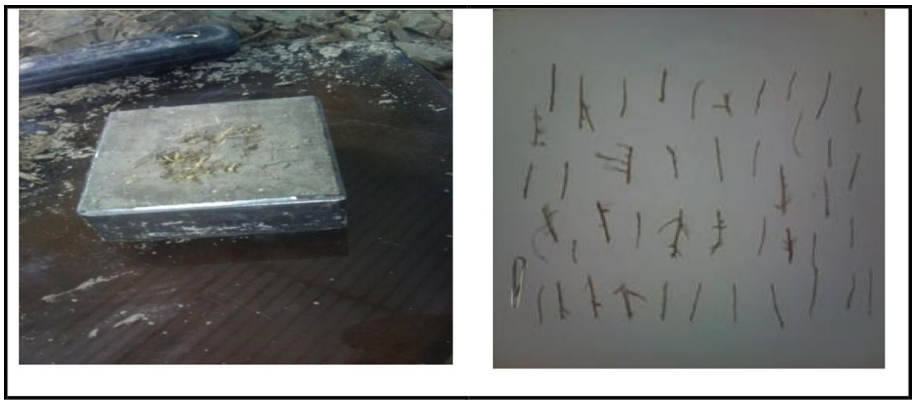


Fig. 3 Root density measurement in soil at the Water and Soil Chemistry Laboratory, Soil Conservation and Watershed Management Research Institute



Fig. 4 Preparation of Vetiver root extracts—Pharmacognosy Laboratory, Faculty of Pharmacy, Mazandaran University of Medical Scienc

(Ar) is the area occupied by the root, (Aw) is the area where the root is observed (sum of the soil and root areas), (ni) is the number of roots in the bundle (i) and (ai) is the average cross-sectional area of the roots in the bundle Haghighi and Sharifi [7]. The cross-sectional area of the roots in the sample molds with the size (6 × 6 cm) was measured to measure the direct shear stress of the soil and their weight was also determined Sharifi [3]. They were dried in the shade at room temperature to prepare for further analysis. Root diameter was measured using a digital caliper [7]. Plant root extracts were prepared using methanol/water (80:20, v/v) solvents via the soaking method (Fig. 4). Solvents were separated from the extracts using a rotary evaporator, stored at 4 °C, and subsequently analyzed Davoodi et al [13]. The collected data—including soil properties, direct shear strength of soil along with Vetiver roots, diameter, weight and yield of Vetiver root extract—were statistically analyzed using one-way analysis of variance (ANOVA), Analysis of variance and Duncan's multiple range test were performed along with bivariate correlation analysis using SPSS software (version 16.0). The results were analyzed and presented accordingly.

3 Equations

Applied formulas for soil shear stress calculations:

A new evaluation of Vetiver (Chrysopogon zizanioides) for slope stabilization and soil adaptation in a temperate and cold mountainous region using direct soil shear stress measurement by solving the equations. As a result, the assumptions are: At any given slope, the soil shear force affects the weight of the plant roots. In this context, there will be three governing equations for determining the direct soil shear (Eq. 1), (Eq. 2), (Eq. 3) and one governing equation for calculating root density in the soil (Eq. 4), which will be solved using these methods:

$$\tau = C + \sigma \tan(\varphi) \tag{1}$$

In Eq. (1), to calculate (τ) the soil shear force, the parameter (C) is the cohesion, (øn) is the force, (tan (ϕ)) is the internal friction angle. The internal friction angle (ϕ) can be determined using the stress coefficient, with the opposite side and the adjacent side:

$$(\varphi) = \frac{a1}{a2} \tag{2}$$

In Eq. (2), the calculation of (ϕ) the internal friction angle is known with the parameter (a_1) is the opposite side, (a_2) is the adjacent side. The direct shear stress of the soil can be determined by the shear force coefficient:

$$\text{Shear Stress} = \frac{\text{Shear Force}(\tau)}{\text{Area of specimen}\left(\text{cm}^2\right)} \tag{3}$$

In Eq. (3), the final calculation of the direct shear stress of the soil with the determined value of shear force (τ), soil shear stress (kPa) measured in the sample area.

Applied formulas for calculating root density in soil:

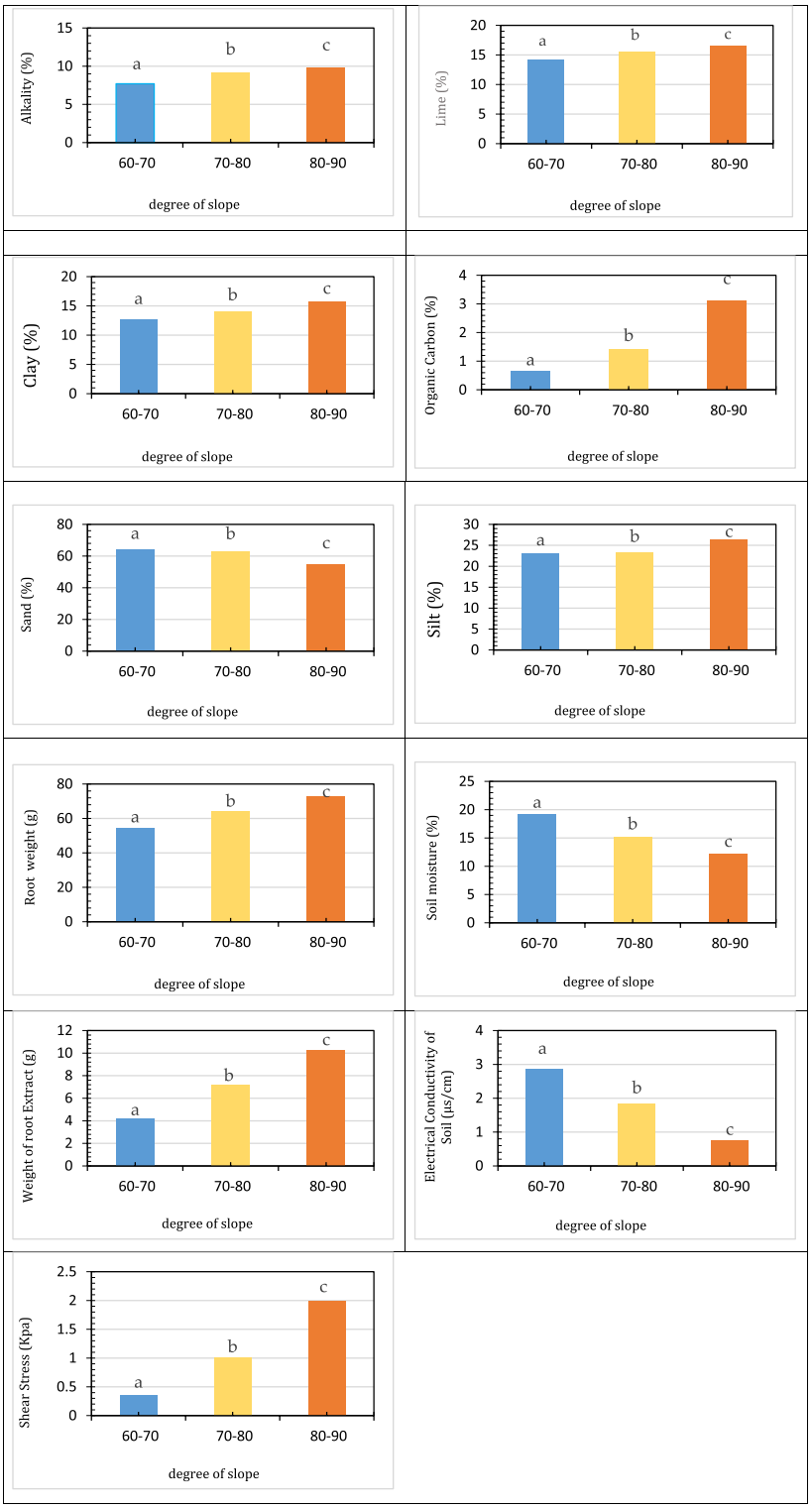


Fig. 5 This figure shows a good correlation between the data. The values are grouped into three levels based on Duncan's multiple range test (Narmab Dam—Golestan Province), which shows the comparison between the measured data

Table 1 Results of one-Way ANOVA for the Mean Percentage of Soil Parameters, Shear Stress, Root Weight, and Vetiver Extract Weight

Source		Sum of squares	df	Mean square	F F-Statistic	Sig
Soil	Slope					
pH	The third level (80–90 degrees)	7.24	2	3.62	13.03	0.00
	Second level (70–80 degrees)	4.84	2	3.94	8.27	0.00
	First level (60–70 degrees)	3.65	2	2.37	6.02	0.00
OC	The third level (80–90 degrees)	9.34	2	4.67	113.70	0.00
	Second level (70–80 degrees)	7.73	2	3.98	80.55	0.00
	First level (60–50 degrees)	4.96	2	2.00	60.90	0.00
TVN	The third level (80–90 degrees)	8.67	2	4.33	42.90	0.00
	Second level (70–80 degrees)	6.09	2	4.00	40.44	0.00
	First level (60–70 degrees)	4.96	2	2.65	36.18	0.00
CLAY	The third level (80–90 degrees)	13.52	2	6.76	144.85	0.00
	Second level (70–80 degrees)	9.21	2	5.56	130.83	0.00
	First level (60–70 degrees)	8.31	2	3.49	127.41	0.00
SILT	The third level (80–90 degrees)	21.07	2	10.53	1.15	0.37
	Second level (70–80 degrees)	18.19	2	9.39	1.20	0.00
	First level (60–70 degrees)	16.77	2	7.67	0.98	0.00
K	The third level (80–90 degrees)	0.06	2	0.03		
	Second level (70–80 degrees)	0.04	2	0.01		
	First level (60–70 degrees)	0.00	2	0.00		
MOUSTURE	The third level (80–90 degrees)	54.14	2	27.07	518.44	0.00
	Second level (70–80 degrees)	68.08	2	35.77	496.42	0.00
	First level (60–70 degrees)	98.35	2	42.03	399.28	0.00
EC	The third level (80–90 degrees)	6.61	2	3.30	992.33	0.00
	Second level (70–80 degrees)	8.04	2	5.99	884.11	0.00
	First level (60–70 degrees)	9.93	2	7.00	641.83	0.00
SAND	The third level (80–90 degrees)	161.74	2	80.87	3.92	0.08
	Second level (70–80 degrees)	196.52	2	98.03	4.52	0.00
	First level (60–70 degrees)	210.74	2	110.00	5.17	0.00
Root weight	The third level (80–90 degrees)	499.28	2	249.64	21.98	0.00
	Second level (70–80 degrees)	395.98	2	190.05	19.32	0.00
	First level (60–70 degrees)	308.00	2	179.91	16.61	0.00
Extract weight	The third level (80–90 degrees)	54.60	2	27.30	599.34	0.00
	Second level (70–80 degrees)	42.50	2	24.70	409.55	0.00
	First level (60–70 degrees)	36.41	2	21.34	387.17	0.00
Shear stress	The third level (80–90 degrees)	4.04	2	2.02	18.86	0.00
	Second level (70–80 degrees)	3.60	2	1.91	17.62	0.00
	First level (60–70 degrees)	2.28	2	1.73	15.77	0.00

$$RAR = \frac{Ar}{Aw} \sum^{i} ni \frac{ai}{Aw} \tag{4}$$

In equation (4), the calculation of the root abundance (RAR) in the soil is determined by the parameters (Ar) area occupied by the root, (Aw) total area of soil and root, (i) in the bundle, (ni) number of roots in the bundle, (ai) average cross-sectional area of roots

in the bundle. The results of the direct soil shear stress measurement calculations can be compared in the following graphs (Fig. 5).

4 Results

In this study, soil slope and shear strength were evaluated along with key soil properties. At different slopes, the Vetiver root system significantly increased root area ratio (RAR) proportional to the applied shear stress of 18.43 kPa. As a result, the presence of Vetiver roots increased soil cohesion by 199%, reduced soil internal friction angle by 78.13%, and improved overall soil shear strength by 27.37%. These results highlight the important role of Vetiver roots in soil stabilization on sloping lands. Data obtained from analysis of variance showed that there was a significant relationship between soil properties such as moisture, organic carbon, lime, salinity, alkalinity, potassium, and soil clay at three levels with different degrees of slope. There is a significant relationship between the weight of Vetiver roots and the acidity factor, organic carbon, lime, clay, moisture, salinity and shear stress of the soil at the one percent level ($p \leq 0.01$) and there is no correlation between the amount of silt and sand in the soil. There is also a significant difference between the weight of the extract and the acidity, organic carbon, lime, clay, potassium, moisture, salinity and shear stress of the soil at the one percent level ($p \leq 0.01$) and with the amount of sand in the soil at the five percent level ($p \leq 0.01$) (Table 1). According to the results of the direct soil shear stress tests with the weight of Vetiver roots and the weight of Vetiver root extract, it can be stated that the resistance and adaptation of Vetiver plants on steep slopes are performed intelligently. In these environmental conditions, the biological activities of Vetiver plants have increased, which is why the relative weight of the plant extract has also increased with the change and increase in slope. The type of adaptation function in Vetiver plant increases weight of its roots at different degrees of slope to achieve better adaptation to the environment by increasing the weight and development of its roots in the soil (Table 2). According to the results of this study, it can be concluded that the reason for the increase or decrease in the amount of Vetiver plant extract at high altitudes and steep slopes depends on their ability and adaptability and the high potential of Vetiver plant in increasing resistance. Soil cutting is a strong reason for its intelligent performance. The correlation between soil characteristics, root weight and Vetiver plant extract weight in (Table 3) shows that there is a significant relationship between soil characteristics (acidity, organic carbon, lime, clay, sand, silt and soil moisture) and the weight of Vetiver plant root extract in the Narmab Dam area. In contrast, there is no significant relationship between soil potassium factor and the amount of root weight and Vetiver root extract weight in the same location. There is also a significant relationship ($p \leq 0.01$) between the rate of soil slope changes of the lateral slope of the Narmab-Golestan dam reservoir and the weight of the Vetiver plant root with the soil characteristics (acidity, organic carbon, lime, clay, sand, silt, moisture and electrical conductivity) of this area and soil shear stress (Table 3). By Comparing the average data obtained from (Fig. 6a, b, c, d, f) respectively shows that in a mountainous, temperate and humid climate, with increasing soil slope from the first level a, (60–70 degrees), to the second level b, (70–80 degrees), to the third level c, (80–90 degrees), and With increasing altitude above sea level, and decreasing humidity level in the region,

Table 2 The result of shear stress and Vetiver plant weight (The side slopes of Narmab Dam Reservoir—Golestan Province)

Source of variation	First level (slope 60–70 degrees)	Second level (slope 70–80 degrees)	The third level (slope > 80°degrees)
Root weight (g)	2 ± 0.4	4 ± 0.7	6.2 ± 0.6
	5 ± 0.6	7 ± 0.2	9 ± 0.1
	5.5 ± 0.8	7.2 ± 0.7	10 ± 0.3
Shear stress (kPa)	1.46 ± 0.9	7.2 ± 05	1.57 ± 0.6
	2.15 ± 0.8	2.59 ± 0.3	2.38 ± 0.9
	3.10 ± 0.3	3.55 ± 0.7	3.49 ± 0.5

the alkalinity (22.7%), soil organic carbon percentage (19.9%), soil lime percentage (18.8%), soil clay percentage (16.7%), and soil silt percentage (7.6%) decrease. Also, comparing the average data obtained from the results (Fig. 6c, e, h), respectively, shows that in mountainous, temperate, and humid climates, the percentage of soil moisture (20%), soil electrical conductivity (13.4%), and soil sand percentage (8.6%) increase. The Comparison of the average data obtained from the results (Fig. 6g) shows that the weight of Vetiver plant roots in the soil increases. In fact, with increasing weight of Vetiver plant roots, its stability and adaptability increase by about (15.5%). The Comparison of the average data obtained from the results (Fig. 6i) shows that, the weight of Vetiver root extract increases by about (13.6%). The Comparison of the average data from the results (Fig. 6k) shows that, with a maximum shear stress value (18.43 kPa), the shear strength of Vetiver roots in the soil increases by about (17.7%). Overall, these results indicate that soil composition and Vetiver root development are strongly affected by slope, altitude and humidity, highlighting the important role of this plant in soil stabilization in temperate and cold mountainous conditions. In temperate and cold mountainous conditions, increasing soil slope (60–70 degrees → 70–80 degrees → >80°degrees), altitude and decreasing humidity significantly affected soil properties and Vetiver root development (Fig. 6). Soil alkalinity, lime, organic carbon and clay increased, while sand, moisture, silt and electrical conductivity reduced. At the same time, the root weight and root extract of Vetiver increased with slope and altitude, increasing the stability and adaptability of the plant. Potassium content was not significantly related to the root weight and root extract of Vetiver in these climatic conditions. These findings highlight the strong influence of topography and microclimate on soil composition and Vetiver yield, highlighting its role in soil stabilization in temperate and cold mountainous regions.

5 Tables

In this study, the data obtained from the analysis of variance of Vetiver plant roots at three levels with different degrees of slope from the lateral slopes overlooking the Narmab Dam reservoir located in Golestan Province are shown in (Table 1).

Data obtained from (Table 2), it is possible to understand the type of plant performance and growth in response to environmental stresses. At the first level, the weight of the plant root is less than at the second and third levels, and in the results of measuring soil shear stress, the amount of soil shear force at the first level is less than at the second and third levels. In fact, the plant changes its weight to create the necessary shear resistance in response

Table 3 The result of Pearson's bivariate correlation between soil factors, shear stress with root weight and extract weight of Vetiver plant (The side slopes of Narmab Dam Reservoir—Golestan Province)

Source		pH	OC	TVN	CLAY	SILT	K	MOISTURE	EC	SAND	T
Root weight(g)	Pearson Correlation	0.81**	0.91**	0.95**	0.92	0.35	0.93**	−0.90**	−0.93**	−0.64	−0.93**
	Sig. (2-tailed)	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.06	0.00
	N	9	9	9	9	9	9	9	9	9	9
Extract weight	Pearson Correlation	−0.88**	0.96**	0.96**	0.98**	0.45	0.99**	0.97**	−0.99**	−0.70**	0.92**
	Sig. (2-tailed)	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00	.00
	N	9	9	9	9	9	9	9	9	9	9
Root × Slope (The mutual effect of slope degree on root weight)	Pearson Correlation	−0.89**	0.91**	−0.93**	0.95	0.95**	.a	−0.97**	−0.87*	−0.95**	0.91**
	Sig. (2-tailed)	0.00	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.07	0.00
	N	9	9	9	9	9	9	9	9	9	9

aCannot be computed because at least one of the variables is constan

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

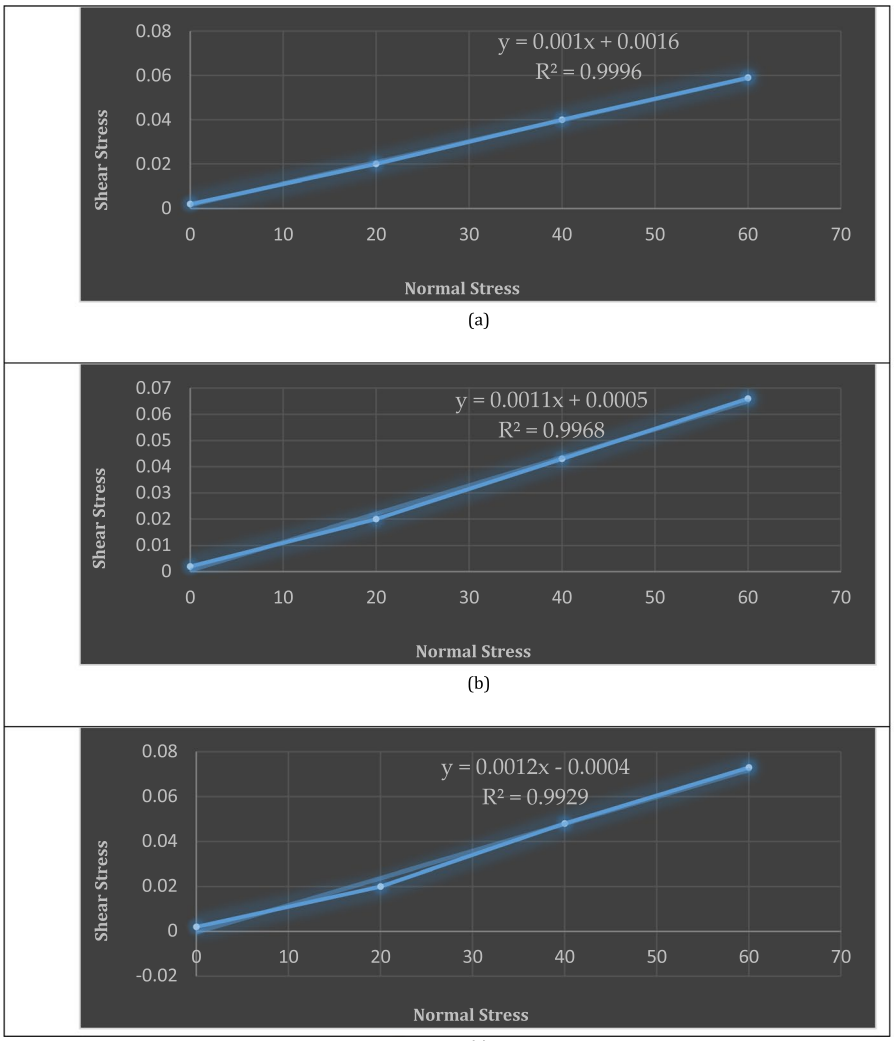


Fig. 6 This figure shows a good correlation between the data. The values are grouped into three levels based on Duncan's multiple range test (Narmab Dam—Golestan Province), which shows the comparison between the measured data

to soil shear force. Therefore, the results of measuring the weight of Vetiver plant roots are directly related to the amount of soil shear force (Table 2):

According to the results of this study, there is a significant relationship ($p \leq 0.01$) between the soil slope changes of the lateral slope of the Narmab-Golestan Dam reservoir and the weight of the Vetiver plant roots with the soil characteristics (acidity, organic carbon, lime, clay, sand, silt, moisture, and electrical conductivity) of this area and soil shear stress (Table 3):

6 Figures

The Comparison of the average data obtained from (Fig. 6) shows that in a mountainous, temperate and humid climate, the soil slope increases from the first level a, (60–70 degrees), to the second level b, (70–80 degrees), to the third level c, (80–90 degrees), with increasing soil slope.

7 Discussion

This study, which was conducted with the aim of analyzing the variance and correlation between soil, root, and Vetiver plant extract factors, shows that there is a significant relationship between soil characteristics (alkalinity, organic carbon, lime, clay, sand, and potassium, and soil moisture) and root weight and Vetiver root extract weight on the lateral slope of the Narmab-Golestan Dam. The moisture content, organic carbon, potassium, lime, acidity, salinity, and soil texture are significantly different at three levels with different degrees of slope, and it is a fact that silty soil does not show a significant difference at three levels with different slopes. With increasing acidity, organic carbon, lime, clay, and silt, root weight, root extract weight, and soil shear stress increase. However, with increasing slope, moisture percentage, electrical conductivity, and soil sand decrease. Therefore, there is a relationship and correlation between the weight of Vetiver plant and the amount of alkalinity, organic carbon, lime, clay, potassium, moisture, electrical conductivity and shear stress of the lateral slope of the soil of the Narmab-Golestan Dam at the ground level at the one percent level ($p \leq 0.01$). And at the same time, there is no significant relationship and correlation with the percentage of silt and sand. Also, the results of the correlation of the weight of Vetiver root extract with alkalinity, organic carbon, lime, clay, potassium, moisture, electrical conductivity, shear stress of the soil of the Narmab-Golestan Dam at the one percent level ($p \leq 0.01$) and with the percentage of sand at the surface ($p \leq 0.05$). Therefore, according to the results of the direct shear stress tests of the soil and the weight of Vetiver root with the amount of acidity, organic carbon, lime, clay, potassium, moisture and electrical conductivity of the soil at the %1 level, there is a significant relationship. ($p \leq 0.01$) and the correlation of resistance and adaptation of Vetiver plant on steep slopes is done intelligently, Vetiver plant increases its root weight with increasing slope degree on the lateral slope of Narmab-Golestan Dam. Considering that only some plants are able to adapt and increase their height with increasing altitude Polaki Khoshkrou et al [14]. The results of this study show that at high altitudes and steep slopes, it depends on their ability and adaptation and the proper performance of Vetiver in increasing the shear strength of the soil has led to its adaptation Forouzeh et al. [15], Jamshidi et al [16]. The results of this study are consistent with the results of the study on the effect of altitude on the quantitative and qualitative characteristics of yarrow Bajalan et al [17], the effect of altitude on Rosmarinus officinalis L. Dehghani Bidgoli [27], the effect of altitude on Artemisia Mahdavi et al [18], the effect of altitude on Tanastum polycapalum Aghaabbasi and Bibak [19], the effect of altitude on Heracleum anisactis Mahdavi and Rahmani [20]

and the effect of altitude on mountain tea (Stachys lavandulifolia). On the other hand, the results of this study are consistent with the results of some studies on the effectiveness of Artemisia rexburghiensis essential oil in Himalayan grasslands Haidar et al. [21]. They investigated the performance of yarrow (Achillea millefolium) essential oil in the "Siah Bisheh" habitat of Mazandaran province Azarnivand et al. [26] and Arianfar et al. [25] on wormwood species in the "Sawad Kooh" region and stated that with increasing altitude, the performance and amount of essential oil decrease Akramian et al. [22]. They also agree with the results of a study that investigated the effect of gas roots on increasing soil adhesion and shear strength along the "Kashf Rood" river Roshan Nasab et al. [23]. They are consistent with the results of a study that investigated the effects of tree shear strength on the stability of the Bashar River Hoque et al [24]. There is a significant relationship between soil shear strength and soil containing Vetiver roots in Tehran. The level of resistance of plants to harsh environmental conditions is the result of their intelligent performance. Vetiver plants consciously defend themselves against environmental factors.

8 Conclusion

This study represents the first experimental application of Vetiver (Chrysopogon zizanioides) for slope stabilization in the world. The results showed that Vetiver significantly increased soil shear strength on slopes of 60–70°, 70–80° and 80–90°, with increases ranging from 26.99 to 36.67%. The increase in root biomass, diameter and extract yield indicates an adaptive response of the plant to environmental stresses, partly through the production of secondary metabolites. Vetiver roots increased soil cohesion by 200%, reduced the soil internal friction angle by 78.19% and improved tensile strength (120–89 MPa), indicating the plant's ability to enhance the mechanical properties of soil under shear stress. It was found that soil characteristics and shear strength varied with slope, elevation and soil properties, and Vetiver root density (RAR) and root weight increased in response to these stresses. The highest concentrations of chemical and structural compounds in Vetiver roots were observed on the steepest slopes, indicating improved functional performance of the plant under challenging conditions. Finally, it can be stated that the hypotheses of this study are plausible. Given its strong adaptability, robust root system, and dual role in soil stabilization and production of bioactive compounds, Vetiver is recommended for use in slope pastures, roadside embankments, reservoir walls, and other watershed management applications. Its integration into land management strategies can reduce soil erosion, landslides, and subsidence, while providing ecological and economic benefits and contributing to sustainable slope stabilization.

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Author contributions
All authors contributed to the study conception, design, data collection, analysis, and manuscript preparation. All authors read and approved the final manuscript.

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Data availability
The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
No ethical approval was required for this study.

Consent for publication
Informed consent for publication is "Not applicable" in this study.

Competing interests
The authors declare no competing interests.

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