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# *Vetiveria zizanoides* Plantation for Slope Stabilization in Kuwait: A case study

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**Due to the increased awareness of environmental issues especially in the degraded soils in recent years, importance of using vegetation as a natural bio-engineering tool in slope stabilization is gaining momentum. Cost effectiveness and environmental friendliness of bioengineering methods compared to concrete constructions, are the major advantageous points. Vetiver was used in soil stabilization projects in various places successfully for many years. Current study evaluates the performance and investigates the effectiveness of Vetiver in slope stabilization under Kuwait's harsh environmental conditions. The results indicated that performance of Urlikal, ODV-3 and ODV-7 was superior in roadway embankment site and Vetiver had successfully reduced 56% and 91% of water and soil erosion respectively when compared to control thus played a significant role in slope stabilization. Slight improvement in the physical property of soil and silt and clay percentage was also obtained by planting Vetiver thus makes it suitable for landscaping.**

**Keywords**: Bioengineering, slope stabilization, vetiver, erosion, landscaping.

## INTRODUCTION

Slope stabilization of embankments is a key factor for the prevention of surface runoff and soil erosion. Removal of top soil by water, wind and waves results in the loss of soil fertility which makes the land barren leading to desertification.

Kuwait's soil is very fragile, composed mostly of sand, not fully developed, and the top horizon is a very thin layer that is easily eroded with slight movement of wind [1]. Over the years various techniques have been evolved and implemented to prevent soil erosion and slope stabilization. Physical stabilization techniques aim at reducing the potential swell pressure and percent of the expansive soil without altering the soil chemistry [2]. Several reinforcement methods are available for stabilizing expansive soils. These methods include stabilization with chemical additives, rewetting, soil replacement, compaction control, moisture control, surcharge loading, and thermal methods. All these methods may have the disadvantages of being ineffective and expensive [3].

Soil bio-engineering is an alternative, cost effective method which utilizes plant material, living or dead, to alleviate environmental problems such as shallow, rapid landslides and eroding slopes and stream banks [4].

Vegetative planting is one of the approach in soil bioengineering which is the conventional planting of grasses, forbs and shrubs to prevent surface erosion. This is one of the most common ways to prevent soil erosion on both residential and commercial landscape areas such as roadway embankments. Plant roots grow deep into the ground, binding the soil and thus increase soil compactness which in turn prevents it from runoff. This also helps in improving the soil properties such as infiltration rate, fertility, microbial activities and also contributes to the beautification of the area.

Kuwait's soil is arid, poor in organic material and moisture content [5]. It is moderate to very shallow in

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**Fig 1**. Overview of the selected site with Vetiver plantation at Surra, Kuwait.

depth and the texture ranges from sand to loamy sand with low mineral holding capacity with sparse vegetation and characterized by low organic matter, nitrogen, phosphorous, and alkaline in nature due to high amounts of calcium content [6]. Plants used for vegetative planting along slopes are selected based on their adaptability, growth performance and potential under the prevailing local arid conditions for their aesthetic looks, soil stabilization, and afforestation values. The selected plants should be non-invasive, less demanding and produce deep roots.

*Chrysopogon zizanoides* L. Roberty, previously known as *Vetiveria zizanoides* L. Nash, a xerophytic and hydrophytic grass has been proven in several tropical countries to be efficient in sand stabilization, soil and water conservation, erosion control, reclamation of degraded lands, soil reclamation, ecological rehabilitation and remediation of soils contaminated with heavy metals [7]. Vetiver is a densely tufted perennial grass with stiff leaf blades belonging to the Poaceae family. It is a fast growing grass with the characteristics of both grass and tree by having profusely grown, deep penetrating root system that can both prevent erosion and control shallow movement of surface earth mass [8]. Vetiver roots are stronger and deeper than the tree roots per unit area. Thick, dense, massive roots which can grow upto 3.6 m in 12 months can bind the soil particles together and make it very difficult to dislodge [9]. It is a non invasive perennial clump grass, is able to grow in a wide range of soil types and pHs (pH 3 to 11), drought, salinity (Electrical Conductivity 8 $dSm^{-1}$) and is heavy-metal tolerant, noncompetitive with other plants, and has very long and strong roots (average stensile strength MPa 75) [7]. Vetiver Grass (*Chrysopogon zizanoides*) has been internationally demonstrated to be a very effective species of steep slope stabilization and flood mitigation in highway embankments [10,11].

Considering the characteristic of Vetiver, a pilot scale study to evaluate its adaptability and performance in slope stabilization at a roadway embankment site was conducted by Kuwait Institute for Scientific Research (KISR).

## MATERIALS AND METHODS

### Site Selection

A site of 600 $m^2$ slope ($13^o$) was allotted by the Public Authority for Agriculture and Fish Resources (PAAFR) of Kuwait at Surra (N $29^0$ 19.152’ E $048^0$ 00.889’), Kuwait city to perform the study, (Fig 1).

### Experimental Design

Randomized Complete Block Design (RCBD) with five replication of 10 cultivars and four slips of each cultivar per replication was used in this study. A slope of 55m was divided into five 10m sections and five 1m section (control); each section representing a replicate (width

**Fig 2**. Vetiver root length experiment.

10m) (Fig. 2). Each 10m x 10m section accommodated 10 cultivars and each cultivar was planted in 1m x 10m sections. Plant and row spacing was 25 cm and 1m respectively, in each section. In each row there were four planting holes with three slips per planting hole for each cultivar. In each replication, 120 slips of each cultivar were planted in 40 planting holes. Control plot was devoid of any plantation.

**Vetiver Cultivars Used**

The selected 10 sterile vetiver cultivars (ODV-3, ODV-7, ODV-9, ODV-13, ODV-14, ODV-16, ODV-23, Urlikal, Morocco, and Sunshine) were procured from international sources.

**Planting**

The selected site was prepared by clearing weeds, trash, rocks, large dirt clods, and other debris and the top soil was loosened. Drip irrigation system was installed prior to planting and the selected cultivars were planted according to the proposed layout. The backfill soil mixture was prepared using peat moss, perlite, and agricultural soil (1:1:1v/v). The plants were irrigated daily for a period of 15 min. The growth of the plants was monitored periodically. The physical and chemical properties of soil mix used for refilling of planting holes were analyzed prior to planting.

**Sample Analysis**

Soil, planting medium, and water samples were collected from the site and their physical and chemical properties were analyzed by Soil Chemistry Laboratory of AAD, and Central Analytical Laboratory of KISR. The following parameters were analyzed:

• Soil and Planting medium: Particle density, bulk density, porosity, saturation percentage, pH, electrical conductivity (EC), calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), chloride (Cl), sulphate (So4), nitrate (NO3), carbonate (CO3), and bicarbonates (HCO3).
• Water: pH, EC, total dissolvable salts (TDS), calcium, potassium, magnesium, sodium, boron, sulphate, carbonate, bicarbonates, nitrate, and chloride.
• Plant Growth Parameters: Data on plant height, canopy, and number of tillers were recorded periodically after the establishment period of one month. Additionally, canopy cover, (the area within the vertical projection of a line just circumscribing the plants) and crown volume were calculated from the recorded plant height and canopy using the following formulae:

Canopy Cover = $\frac{1}{4} \pi D1 * D2$ ....... (1)
Crown Volume= $\frac{1}{6} \pi D1 * D2 * h$ …(2)

Where; D1 is the horizontal diameter of the crown, D2 is the vertical diameter of the crown, h is the height of the plant, and л equals 3.14. Relative growth in plant height, canopy, and number of tillers was calculated as follows:

Relative growth (%) = [(Final value - Initial value) / Initial value) X 100] … (3)
To measure the effectiveness of Vetiver system in slope

**Table 1**. Physical and Chemical Properties of Planting Medium.

| | Parameters | Values |
|---|---|---|
| Physical Properties | Bulk Density (g/cm$^3$) | 1.57 |
| | Porosity (%) | 39.85 |
| | Saturation Percentage (%) | 40.00 |
| Chemical Properties | pH | 7.20 |
| | EC (mS/cm) | 3.58 |
| | Ca (mg/kg) | 127.20 |
| | K (mg/kg) | 100.80 |
| | Mg (mg/kg) | 38.96 |
| | Na (mg/kg) | 135.20 |
| | $SO_4$ (mg/kg) | 261.20 |
| | Cl (mg/kg) | 262.00 |
| | $HCO_3$ (mg/kg) | 71.44 |
| | $CO_3$ (mg/kg) | <1.00 |
| | $NO_3$ (mg/kg) | 80.45 |

**Table 2.** Chemical Analysis of Irrigation Water Utilized at the Roadway Embankment Site.

| Parameters | Initial | Mid | Final |
|---|---|---|---|
| pH | 7.10 | 7.10 | 6.60 |
| EC (mS/cm) | 0.86 | 0.62 | 0.89 |
| TDS (mg/l) | 417.00 | 391.00 | 431.00 |
| Ca(mg/l) | 38.20 | 36.80 | 45.70 |
| K(mg/l) | 10.20 | 11.50 | 12.20 |
| Mg(mg/l) | 9.20 | 8.88 | 8.76 |
| Na(mg/l) | 86.20 | 83.40 | 87.76 |
| B (mg/l) | <0.05 | <0.05 | 0.20 |
| $SO_4$(mg/l) | 114.00 | 108.20 | 111.00 |
| $HCO_3$(mg/l) | 38.05 | 42.20 | 54.74 |
| $CO_3$ (mg/l) | <0.10 | <0.10 | <0.10 |
| $NO_3$ (mg/l) | 56.20 | 49.50 | 40.53 |
| Cl (mg/l) | 132.00 | 112.80 | 144.00 |

stabilization and in controlling water and soil erosion, the amount of water and soil eroded per m$^2$ was monitored for planted and unplanted area. Measurements were recorded periodically after the formation of hedge by the Vetiver tillers (210 days after planting) to evaluate the effectiveness of Vetiver hedge as filter and obstruction to water and soil erosion in the slope when compared to control. As mentioned above, Vetiver has an extensive root system which grows rapidly and forms a massive soil binding system, ideal for soil and water conservation when planted as a hedgerow along contour lines [12,13].

A separate study was also conducted to compare the root and shoot growth of different Vetiver cultivars procured from various parts of the world. Since, monitoring of the root growth at the experimental site was practically difficult, selected cultivars were grown in polyvinyl tubes of one meter height and 20 cm diameter (Fig 2). The selected cultivars were: ODV-7, ODV-9, ODV-12, ODV-13, Sunshine, Pannimedu, Silent Valley, Madagascar, Morocco, and Urlikal.

Prior to planting, the roots of selected vetiver plants were pruned at 10 cm length and planted in a medium similar to that used in the field. After a period of 180 days after planting the experiment was terminated and the dry weight and length of the root and shoot were measured.

## RESULTS

### Soil and water analysis

Analysis results indicated that planting medium was neutral and weakly saline (Table 1). Irrigation water used was neutral, non saline with acceptable limits of TDS, Ca, Na, Mg, B, $SO_4$, $HCO_3$, $CO_3$ and Cl (Table 2). Slight changes in the physical properties of the soil were noticed at the roadway embankment site. Soil remained slightly alkaline and moderatly saline with low Ca, Mg, and K content and moderate Na content, without any significant changes at the end of the experimental period [14]. While marginal increase in the percentage of silt was noticed, sand percentage had decreased indicating the improvement in the physical property of the soil making it suitable for agriculture and landscaping (Table 3).

### Growth Parameters

The plant growth was monitored continuously throughout the experimental period. Results derived from the analysis on growth parameters - plant height, canopy, basal width, number of tillers, crown volume, and canopy cover indicated that though cultivar ODV-23 produced the highest average plant height, average relative growth in height was highest in cultivar ODV-7. Though the initial height of cultivar Sunshine was high (39.5 cm) at 270 DAP, cultivar ODV-23 recorded the highest growth (129.95 cm) followed by cultivars Urlikal, Morocco and ODV-16. Average relative growth in height was the highest in cultivar ODV-7, but all the cultivars except Morocco and Sunshine exhibited similar growth (Table 4). Average plant canopy at 270 DAP was highest in cultivar ODV-7. However, there was no significant variation in canopy among cultivars at 270 DAP. The highest average relative growth in canopy was recorded in cultivars Urlikal and ODV-3 (Table 5). Additionally,

**Table 3**. Physical and Chemical Properties of Soil.

| | Parameters | Initial | Mid | Final |
|---|---|---|---|---|
| Physical Properties | Sand (%) | 85.00 | 80.00 | 75.60 |
| | Silt (%) | 7.00 | 11.00 | 15.00 |
| | Clay (%) | 8.00 | 9.00 | 8.40 |
| | Texture | Loamy sand | Loamy sand | Sandy loam |
| | Bulk Density (g/cm$^3$) | 1.47 | 1.44 | 1.54 |
| | Porosity (%) | 49.52 | 42.54 | 40.22 |
| | Saturation Percentage (%) | 28.45 | 33.33 | 26.00 |
| Chemical Properties | pH | 7.50 | 7.20 | 7.70 |
| | EC (mS/cm) | 5.48 | 5.20 | 5.30 |
| | Ca(mg/kg) | 171.62 | 143.33 | 144.56 |
| | K(mg/kg) | 31.01 | 36.67 | 34.96 |
| | Mg(mg/kg) | 60.34 | 59.67 | 62.65 |
| | Na(mg/kg) | 164.70 | 160.33 | 168.53 |
| | $SO_4$(mg/kg) | 672.07 | 677.00 | 652.33 |
| | Cl (mg/kg) | 110.41 | 104.33 | 106.40 |
| | $HCO_3$(mg/kg)) | 25.78 | 24.43 | 27.37 |
| | $CO_3$ (mg/kg) | <1.00 | <1.00 | <1.00 |
| | $NO_3$ (mg/kg) | 71.61 | 67.12 | 68.36 |

**Table 4.** Average Plant Height of Various Cultivars at the Roadway Embankment Site

| Cultivar | Average Height (cm) | | | | Average Relative Growth in Height (%) |
|---|---|---|---|---|---|
| | Initial | 90 DAP | 150 DAP | 270 DAP | |
| ODV - 3 | 23.95 ab | 70.60 ab | 95.20 | 107.05 ab | 356.86 bc |
| ODV - 7 | 20.85 a | 68.60 a | 96.20 | 108.70 ab | 395.18 c |
| ODV - 9 | 24.80 ab | 70.35 ab | 100.00 | 114.40 abc | 348.10 bc |
| ODV-13 | 24.90 ab | 73.60 ab | 98.25 | 111.15 ab | 350.91 bc |
| ODV-14 | 26.20 b | 79.05 ab | 105.75 | 110.50 ab | 321.07 bc |
| ODV-16 | 26.44 b | 79.61 ab | 102.44 | 116.89 abc | 353.59 bc |
| ODV-23 | 28.50 bc | 101.30 c | 113.00 | 129.95 c | 356.53 bc |
| Urlikal | 28.80 bc | 82.90 b | 109.25 | 123.85 bc | 342.93 bc |
| Morocco | 32.30 c | 82.60 b | 105.05 | 117.60 abc | 266.01 b |
| Sunshine | 39.50 d | 73.35 ab | 90.70 | 105.35 a | 163.95 a |
| Significance | ** | ** | NS | * | ** |

DAP: Days after planting.
The means followed by the same letter are not statistically different at p 0.01.
The data were analyzed using SPSS analysis of variance procedure and Duncan's Multiple Range test.
** = Significant at $P \leq 0.01$ level, NS - Not Significant.

cultivars Urlikal, ODV-3 and ODV-7 exhibited superior average relative growth in basal width (Table 6). Considering the average number of tillers, crown volume and canopy cover and their relative growths, cultivars Urlikal, ODV-3 and ODV-7 were found to be ideal for the roadway embankment sites. Though the average number of tillers, crown volume and canopy cover was higher in cultivar Morocco, their relative growth was poor (Tables 7, 8, and 9 respectively).

**Soil Stabilization.**

Comparison of periodic amount of soil and water eroded

**Table 5.** Comparison of Average Plant Canopy of Various Cultivars at the Roadway Embankment Site.

| Cultivar | Average Canopy (cm) | | | | Average Relative Growth in Canopy (%) |
|---|---|---|---|---|---|
| | Initial | 90 DAP | 150 DAP | 270 DAP | |
| ODV - 3 | 11.20 a | 25.20 abc | 33.60 | 41.90 | 266.87 bc |
| ODV - 7 | 15.10 b | 32.15 d | 38.90 | 44.05 | 153.43 ab |
| ODV - 9 | 13.80 ab | 25.20 abc | 31.55 | 37.50 | 167.84 ab |
| ODV-13 | 13.85 ab | 21.90 a | 28.10 | 34.15 | 149.42 ab |
| ODV-14 | 14.90 b | 22.90 ab | 29.35 | 34.75 | 132.13 a |
| ODV-16 | 16.61 b | 29.22 bcd | 36.67 | 42.17 | 140.57 a |
| ODV-23 | 15.75 b | 28.30 abcd | 34.65 | 39.35 | 152.30 ab |
| Urlikal | 10.50 a | 32.35 d | 38.00 | 43.65 | 306.13 c |
| Morocco | 15.50 b | 31.35 cd | 37.10 | 41.65 | 150.73 ab |
| Sunshine | 13.70 ab | 29.00 bcd | 35.15 | 41.40 | 173.70 ab |
| Significance | ** | ** | NS | NS | * |

DAP: Days after planting.
The means followed by the same letter are not statistically different at p 0.01.
The data were analyzed using SPSS analysis of variance procedure and Duncan's Multiple Range test.
**, * = Significant at $P \leq 0.01$, 0.05 level, NS - Not Significant.

**Table 6**. Comparison of Average Plant Basal Width of Various Cultivars at the Roadway Embankment Site.

| | Average Basal Width (cm) | | | | Average Relative Growth |
|---|---|---|---|---|---|
| Cultivar | Initial | 90 DAP | 150 DAP | 270 DAP | in Basal Width (%) |
| ODV - 3 | 5.70 a | 13.80 abc | 18.35 | 20.60 | 236.43 bc |
| ODV - 7 | 6.85 abcd | 14.40 abc | 18.05 | 20.10 | 203.94 bc |
| ODV - 9 | 6.50 abcd | 13.75 abc | 17.35 | 19.60 | 189.67 abc |
| ODV-13 | 7.55 d | 12.90 ab | 16.55 | 18.60 | 155.74 ab |
| ODV-14 | 6.75 abcd | 12.50 a | 16.05 | 18.35 | 164.21 ab |
| ODV-16 | 9.00 c | 15.44 bc | 19.28 | 21.11 | 126.94 a |
| ODV-23 | 7.30 cd | 15.75 c | 18.45 | 21.35 | 173.10 abc |
| Urlikal | 5.95 ab | 16.00 c | 19.90 | 22.15 | 264.36 c |
| Morocco | 7.10 bcd | 13.70 abc | 17.45 | 20.00 | 165.35 ab |
| Sunshine | 6.25 abc | 12.15 a | 15.55 | 19.55 | 185.82 abc |
| Significance | ** | ** | NS | NS | * |

DAP: Days after planting.
The means followed by the same letter are not statistically different at p 0.01.
The data were analyzed using SPSS analysis of variance procedure and Duncan's Multiple Range test.
**, * = Significant at $P \leq 0.01$, 0.05 level, NS - Not Significant.

**Table 7.** Comparison of Average Number of Tillers of Various Cultivars at the Roadway Embankment Site.

| | Average No. of Tillers | | | | Average Relative Growth |
|---|---|---|---|---|---|
| Cultivar | Initial | 90 DAP | 150 DAP | 270 DAP | in No. of Tillers (%) |
| ODV - 3 | 13.50 ab | 37.90 bcd | 45.20 ab | 52.60 abcd | 266.01 bc |
| ODV - 7 | 17.55 bc | 49.55 d | 57.60 b | 65.65 d | 209.41 abc |
| ODV - 9 | 14.50 ab | 29.75 ab | 36.65 a | 46.80 abc | 199.85 abc |
| ODV-13 | 17.25 ab | 28.20 ab | 35.15 a | 44.75 ab | 160.47 a |

**Table 7** Cont.

| | | | | | |
|---|---|---|---|---|---|
| ODV-14 | 13.90 ab | 24.30 a | 31.80 a | 40.15 a | 190.15 ab |
| ODV-16 | 22.72 d | 45.00 cd | 53.44 b | 61.06 cd | 157.65 a |
| ODV-23 | 21.40 cd | 43.10 cd | 50.75 b | 59.05 bcd | 168.81 a |
| Urlikal | 15.65 ab | 47.40 cd | 55.95 b | 64.60 d | 310.60 c |
| Morocco | 16.90 ab | 36.70bc | 43.95 ab | 53.45 abcd | 214.98 abc |
| Sunshine | 12.80 a | 28.80 ab | 35.65 a | 47.45 abc | 230.99 abc |
| Significance | ** | ** | ** | ** | * |

DAP: Days after planting.
The means followed by the same letter are not statistically different at p 0.01.
The data were analyzed using SPSS analysis of variance procedure and Duncan's Multiple Range test.
**, * = Significant at P ≤ 0.01, 0.05 level, NS - Not Significant.

**Table 8**. Comparison of Average Plant Crown Volume of Various Cultivars at the Roadway Embankment Site.

| | Average Crowm Volume ($m^3$) | | | | Average Relative Growth in Crown Volume (%) |
|---|---|---|---|---|---|
| **Cultivar** | **Initial** | **90 DAP** | **150 DAP** | **270 DAP** | |
| ODV - 3 | 0.0015 a | 0.0345 abc | 0.079 | 0.1209 ab | 8256.58 bc |
| ODV - 7 | 0.0024 ab | 0.0495 bc | 0.111 | 0.1542 b | 4667.67 ab |
| ODV - 9 | 0.0027 ab | 0.0294 ab | 0.069 | 0.1060 ab | 4313.20 ab |
| ODV-13 | 0.0032 bc | 0.0234 a | 0.051 | 0.0809 a | 3049.30 a |
| ODV-14 | 0.0032 bc | 0.0290 ab | 0.064 | 0.0823 a | 3255.37 a |
| ODV-16 | 0.0038 bc | 0.0449 bc | 0.090 | 0.1359 ab | 3952.76 a |
| ODV-23 | 0.0038 bc | 0.0476 bc | 0.082 | 0.1191 ab | 3798.39 a |
| Urlikal | 0.0015 a | 0.0542 c | 0.109 | 0.1567 b | 9892.36 c |
| Morocco | 0.0043 c | 0.0490 bc | 0.098 | 0.1417 b | 2805.43 a |
| Sunshine | 0.0037 bc | 0.0347 abc | 0.073 | 0.1186 ab | 2356.68 a |
| Significance | ** | * | NS | * | ** |

DAP: Days after planting.
The means followed by the same letter are not statistically different at p 0.01.
The data were analyzed using SPSS analysis of variance procedure and Duncan's Multiple Range test. **, * = Significant at P ≤ 0.01, 0.05 level, NS - Not Significant.

**Table 9.** Comparison of Average Plant Canopy Cover of Various Cultivars at the Roadway Embankment Site.

| | Average Canopy Cover ($m^2$) | | | | Average Relative Growth in Canopy Cover (%) |
|---|---|---|---|---|---|
| **Cultivar** | **Initial** | **90 DAP** | **150 DAP** | **270 DAP** | |
| ODV - 3 | 0.0098 ab | 0.0693 abc | 0.1157 abcd | 0.1607 ab | 1648.54 b |
| ODV - 7 | 0.0167 c | 0.1010 d | 0.1483 d | 0.1913 b | 803.53 a |
| ODV - 9 | 0.0145 bc | 0.0595 ab | 0.0946 abc | 0.1294 ab | 841.59 a |
| ODV-13 | 0.0172 c | 0.0464 a | 0.0760 a | 0.1061 a | 572.93 a |
| ODV-14 | 0.0164 c | 0.0505 a | 0.0817 ab | 0.1097 a | 640.18 a |
| ODV-16 | 0.0198 c | 0.0846 bcd | 0.1306 bcd | 0.1733 b | 765.07 a |
| ODV-23 | 0.0194 c | 0.0647 abc | 0.1012 abcd | 0.1317 ab | 714.17 a |
| Urlikal | 0.0079 a | 0.0955 cd | 0.1454 cd | 0.1849 b | 2112.03 b |
| Morocco | 0.0201 c | 0.0866 bcd | 0.1368 cd | 0.1763 b | 666.35 a |
| Sunshine | 0.0014 bc | 0.0673 abc | 0.1139 abcd | 0.1572 ab | 804.08 a |

**Table 9** cont.

| | | | | | |
|---|---|---|---|---|---|
| Significance | ** | ** | * | * | ** |

DAP: Days after planting.
The means followed by the same letter are not statistically different at p 0.01.
The data were analyzed using SPSS analysis of variance procedure and Duncan's Multiple Range test. **, * = Significant at P ≤ 0.01, 0.05 level.

**Table 10**. Comparison of Soil and water Erosion at Roadway Embankment Site

| Details | Planted | Unplanted | Reduction in Erosion (%) |
|---|---|---|---|
| Average Water Eroded (ml/$m^2$) | 194.35 | 441.29 | 55.96 |
| Average Soil Eroded (g/$m^2$) | 4.80 | 56.47 | 91.51 |

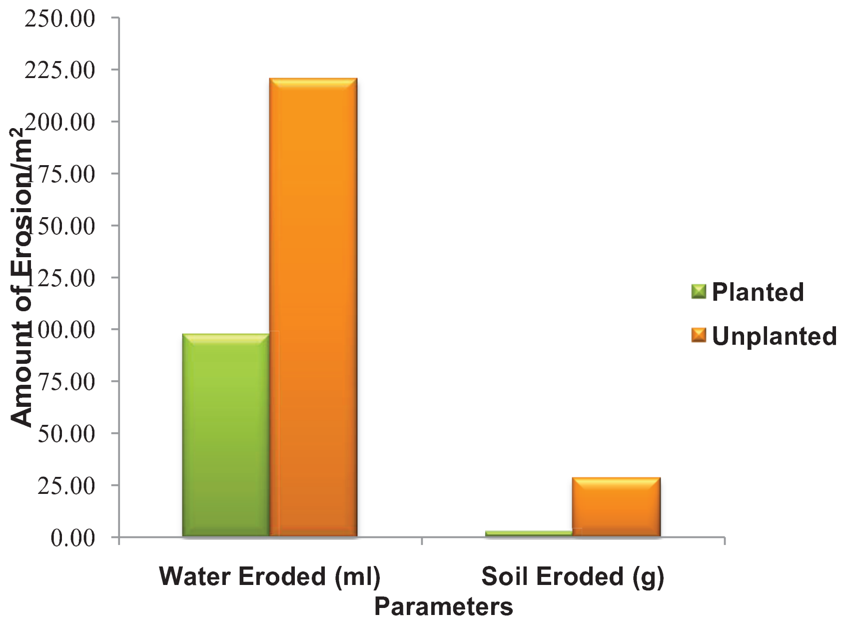


**Fig**. 3. Amount of soil and water eroded at planted and unplanted area at the roadway embankment site, Surra.

in planted and unplanted area ($m^2$) indicated a reduction of 56% and 91% in terms water and soil erosion, respectively when compared to control (Table 10 and Fig 3).

### Root Length

The length and biomass of shoot and root of various cultivars grown in the PVC tubes were analyzed and the results indicated that root length of Vetiver cultivars ranged from 87 to 134 cm in 180 DAP (Fig 4). There was significant variation in root length and shoot weight among cultivars. Though the root length of cultivar Madagascar was the highest (134 cm), performances of cultivars Urlikal, Morocco, ODV-13, Silent Valley and ODV-9 in terms of root length were not significantly different. No significant difference in shoot length and dry root weight at 180 DAP between the cultivars. Shoot weight of ODV-12 was significantly different from all other cultivars (Table 11).

## DISCUSSION

Fibrous rooted shrubs and grasses are the best option to be used for slope stabilization when compared to trees, as the fibrous roots can play a greater role in binding the

**Fig 4**. Vetiver plant at 180 DAP

**Table 11**. Average Length and Biomass of Root and Shoot in Various Cultivars at 180 DAP.

| Cultivar | Root Length (cm) | Shoot Length (cm) | Dry Weight (g) | |
|---|---|---|---|---|
| | | | Root | Shoot |
| ODV-7 | 87.333 a | 111.333 | 23.133 | 393.433 a |
| ODV-9 | 122.000 bcde | 120.667 | 40.467 | 394.900 a |
| ODV-12 | 109.000 bc | 118.667 | 32.867 | 692.867 b |
| ODV-13 | 126.667 cde | 120.667 | 66.267 | 474.167 a |
| Sunshine | 103.000 ab | 128.333 | 33.100 | 470.467 a |
| Pannimedu | 110.667 bcd | 148.000 | 42.333 | 427.833 a |
| Silent Valley | 123.333 cde | 121.667 | 43.500 | 473.300 a |
| Madagascar | 134.000 e | 132.000 | 39.500 | 496.800 a |
| Morocco | 129.333 de | 134.000 | 61.300 | 418.500 a |
| Urlikal | 133.667 e | 122.000 | 77.600 | 286.700 a |
| Significance | ** | NS | NS | * |

DAP: Days after planting.
The means followed by the same letter are not statistically different at p 0.01.
The data were analyzed using SPSS analysis of variance procedure and Duncan's Multiple Range test.
**, * = Significant at $P \leq 0.01$, 0.05 level, NS - Not Significant.

soil particles effectively. Vetiver, which can adapt to the climate of Kuwait with long, fibrous root system, is the best option considering the erosion control and aesthetic effects. The results of this study, confirms the effectiveness of Vetiver in controlling soil and water erosion in slopes ($13^{o}$) by reducing them by 92% and

56% respectively. The findings are supported by the previous studies [15] which stated that Vetiver can grow vertically on slopes steeper than 150% (~56°). Reduction in soil loss from 14.4 t/ha (control) to 3.9 t/ha was recorded in a slope of 1.7% (~ 0.97°) also in India by planting vetiver hedges. Research studies at International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) indicated runoff in vetiver plots were only 44% of that of the control plots on 2.8% slope (~ 1.6°) [9]. Vetiver roots with average tensil strength of 75 MPa can improve the shear strength of soil by 30% and has the potential for slope stabilization [16]. If the plants are pruned at three months interval after the establishment period the profuse tillering can be an aesthetic treat. The performance of the various cultivars at the roadway embankment site indicated that cultivars Urlikal, ODV-3 and ODV-7 were the superior among all the cultivars tested at this site.

## Conclusion

The artificial slopes prevailing in Kuwait can be maintained at low cost through the bioengineering techniques. Construction of concrete checkerboard is usually practiced in Kuwait which is not a natural and sustainable way to protect the slope and needs high investments. Replacing the concrete structures with bio-engineering techniques will have a good aesthetic effect and have long-term positive effects on the physical and chemical properties of degraded soils of Kuwait.

The current study concludes that cultivars Urlikal, ODV-3 and ODV-7 were the best performing Vetiver cultivars in Kuwait's harsh climatic conditions, based on average height, canopy, number of tillers, crown volume and canopy cover and their relative growth when used in roadway embankments. Slight improvement in the physical property of soil and silt and clay percentage can be obtained by planting Vetiver thus makes it suitable for landscaping.

Vetiver was also successfully effective in reducing the water and soil erosion by 56% and 91% respectively when compared to control and hence can be used as the best bioengineering method for slope stabilization in roadway embankments.

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