Effectiveness of vegetative buffer strips at reducing runoff, soil erosion, and nitrate transport during degraded hillslope restoration in northern Iran

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Abstract

Soil and water conservation in natural and cultivated areas is a major concern for humankind. However, there are severe problems with degraded hillslopes due to bare soils in northern Iran, which are one of the most important factors driving land degradation processes. Subsequently, soil erosion, pollutant transport, and/or nutrient impoverishment are affecting large territories; therefore, rapid and inexpensive soil conservation measures need to be implemented. The use of vegetative buffer strips could be an effective strategy to reduce pollutant transport as well as soil erosion. Thus, this research aimed to investigate the possible efficiency of two different vegetative buffer strips composed of vetiver-grass (Chrysopogon zizanioides) and native turf-grass (Festuca arundinacea) at reducing runoff and soil losses as well as nitrate transport on a representative degraded hillslope with bare soils in Mazandaran, Iran. Twelve 10 m² experimental plots were tested over 1 year using a runoff simulator that produced overland flow that corresponded to the 25- and 100-year return period rainfall events. The plots with bare soils had the highest runoff volumes (30.5 and 55.4 L m⁻²), sediment concentrations (101.2 and 430.6 g L⁻¹), and nitrate concentrations (10.4 and 37.6 mg L⁻¹). Vetiver was the most useful tool to reduce runoff, soil loss, and nitrate concentration, with values of 13.4 and 28.6 L m⁻², 13.4 and 90.9 g L⁻¹, and 2.9 and 16.4 mg L⁻¹, respectively. Of the treatments investigated, vetiver provided the most rapid cover and was the most efficient at preventing soil erosion and nitrate transport directly after plantation.

KEYWORDS

hillslope restoration, pollutant transport, runoff simulations, soil erosion, vetiver grass

1 INTRODUCTION

The restoration and optimal recuperation of soils on degraded hillslopes is a major modern concern (Benvenuti & Bretzel, 2017; Dawson, Elbakidze, Angelstam, & Gordon, 2017). The correct use of soil and water resources are considered foundational principles of sustainable development (Fallah, Kavian, & Omidvar, 2016) to insure a secure future for humankind (Alewell, Egli, & Meusburger, 2015). However, excessive intensification of land use through increasing agricultural and silvopastoral areas has led to some adverse consequences such as soil erosion, soil fertility reduction, desertification, and soil and water pollution (Hosseini et al., 2017; Kelarestaghi & Jafarian, 2011; Pulido-Fernández, Schnabel, Lavado-Contador, Miralles Mellado, & Ortega, 2013). Arid and semiarid areas are among the most vulnerable territories to these land degradation processes (Cammeraat, Cerdà, & Imeson, 2010; Zhang, Zhang, Evans, & Huang, 2017). This problem is...
a big concern in Iran, because during the last half century, several researchers have determined that soil erosion rates are increasing (Kavian, Hoseinipoor Sabet, Solaimani, & Jafari, 2017; Mohamadi & Kavian, 2015; Sadeghi, Kiani Harchegani, & Asadi, 2017; Sadeghi, Seghaleh, & Rangavar, 2013; Salehi, Esfandiarpoor Borujeni, Mohajer, & Baqeri Bodagabadi, 2011). Moreover, high overland flow generated from agricultural lands and deforested areas contains a wide range of contaminants with high concentrations of nitrates, phosphorus, or heavy metals (Collins et al., 2010; Shiri et al., 2017).

Soils in semiarid areas that have been left bare after abandonment or land use change are one of the most important environmental factors driving soil erosion in arid and semiarid areas (Hueso-González, Martínez-Murillo, & Ruiz-Sinoga, 2014; Kavian, Golshan, & Abdollahi, 2017; Nearing et al., 2017). Tillage and the overuse of herbicides causes a lack of vegetation cover that leaves soils uncovered and unprotected. Concentrated extreme rainfall events over short periods then lead to large-scale soil and water transport as well as eutrophication of water bodies (Hay, Pittroff, Tooman, & Meyer, 2006; Morgan & Rickson, 1995). Moreover, a lack of vegetation cover also decreases raindrop interception by leaves and increases the negative effect of the splash, destroying soil aggregates and generating rill and inter-rill erosion (Belmonte Serrato & Romero Díaz, 1998; Leuning, Condon, Dunin, Zegelin, & Denmead, 1994).

Sediment transport and runoff generation highly affect nutrients loss from natural and anthropogenic ecosystems on steep slopes with bare soils (Nadal-Romero, Petric, Verachtert, Bochet, & Poensen, 2014). Nitrate is one of the most common contaminants dissolved in surface water that is then able to reach high levels in waterbodies close to agricultural lands (Döring, Brandt, Heß, Finckh, & Saucke, 2005; García-Díaz et al., 2017). Consequently, nitrate can cause eutrophication, the death of aquatic organisms, restricted growth, weakened immune systems, development of stress in some aquatic species (Abdollahi, Kavian, & Sadeghi, 2017; Galloway et al., 2003), and human health problems such as methemoglobinemia and stomach cancer (Steffan, Brevik, Burgess, & Cerdà, 2018).

Best management practices (BMPs) are common tools to mitigate the negative impacts of unsustainable land management. For example, the conservation and use of vegetative buffer strips could be considered effective BMPs against high soil erosion rates and water pollution (Hellberg, Easton, & Davis, 2008; Lam, Schmalz, & Fohrer, 2011). Vegetative buffer strips can contain various types of plants such as grasses, trees, and shrubs or a combination of plants that are embedded down flow from agricultural lands on hillslopes with erodible soils as well as river banks (Dabney, 2003). In other words, vegetative buffer strips include specific plant species that must be passed by runoff before it can get into local waterbodies (Dunn et al., 2011; Otto, Cardinali, Marotta, Paradisi, & Zanin, 2012; Yuan, Bingner, & Locke, 2009).

Vetiver-grass (Chrysopogon zizanioides) is a tropical species native to south and southwest Asia that could be used in vegetative buffer strips. This plant grows naturally on various soil types without high nutrient requirements (Troung, Van, & Pinners, 2011). Vetiver-grass also grows fast, reaching a height of about 50 to 150 cm and a width of approximately 30 cm. The roots of vetiver-grass are scattered, very branched and bulky, and can penetrate to a soil depth from 2 to 4 m (Iranian association for vetiver promotion, 2008).

Several research projects have been carried out to check the applicability of vegetative buffer strips in the qualitative and quantitative control of water and soil losses (i.e., Borina, Vianelloa, Moraria, & Zanib, 2005; Golabi, Iyetar, Minton, Raulerson, & Drake, 2005; Lee, Ilsenhart, & Schultz, 2003). Installation of vegetative buffer strips in the irrigated lands of vulnerable semiarid regions can be useful to mitigate the destructive effects of human activities and consequently improve environmental protection. However, it should be considered as an additional approach for contamination control along with other control measures under field conditions in semiarid areas (Camp-Bescos, Munoz-Carpena, Kiker, Bodah, & Ullman, 2015).

According to Golabi et al. (2005), a vetiver system is efficient for sediment detachment reduction and water quality improvement. Mankin, Daniel, Charles, Stacy, and Wayne (2007) claimed that the type of species utilized as vegetative buffer strips have a considerable effect on pollutant removal. Lee et al. (2003) observed that a mixture of different plant species could improve the vegetative buffer strip utilization with the goal of reducing runoff pollution. However, Hay et al. (2006) reported a low efficiency for a combination buffer strip due to high runoff volume that was generated because it was canaled through a sloping area. Leeds-Harrison, Quinton, Walker, Sanders, and Harrod (1999) indicated that grassy buffers have a significant effect on removal of pollutants. Thus, the literature demonstrates that vegetative buffer strips can be an effective way to reduce soil, runoff, and pollution losses from agricultural fields, but there is still a need to investigate which combination of species and which extension buffer strips will be most effective in hillslope restoration and conservation in different environments (Asbjoenssen et al., 2014; Hernandez-Santana et al., 2013; Hernandez-Santana, Zhou, Helmers, Asbjoenssen, & Kolka, 2010).

The main goal of this research was to assess the possible effect of two different vegetative buffer strips, vetiver-grass and native turf-grass (Festuca arundinacea), in reducing runoff and soil loss as well as pollutant transport on a representative degraded hillslope in Mazandaran, Iran. This area is characterized by a rapidly expanding population, degraded freshwater resources, and increasing concerns about degradation of water and soil resources. To achieve this goal, experiments in $10^2$ m² plots were conducted using a runoff simulator for rainfall events with 25- and 100-year return periods.

2 | MATERIALS AND METHODS

2.1 | Study area

The study area is located in a territory characterized by rain fed farming in Miandorod in the Mazandaran region, Iran (36° 33′N; 53° 10′E). The studied plots are situated in an experimental area chosen to represent the major characteristics of the region, including mean slopes of 15% that are approximately 23 m asl. Based on Dasht-e-Naz station weather data (Sadeghi Raves, 2011), annual rainfall is 789 mm with dry periods commonly occurring during summer (<25 mm per month).
The climate is marine temperate with annual average temperatures of 17°C (Cs in the Köppen climate classification). The soils are Histosols (IUSS-WRB group, 2014) with a clay-loam texture. Organic matter content is high (16%) and average pH is 6.5. Soil depths used to reach 70 cm, but due to agricultural practices, they have been reduced to about 50 cm. Limestone rock fragments are found on the surface and vegetation cover is scarce because of agricultural and pastoral land uses. The most commonly cultivated crop is wheat (Triticum aestivum) and natural vegetation includes steppe plants. Two different stages of plowing are commonly carried out for wheat crops. First, a chisel plow is used to a soil depth of about 20–25 cm during autumn after harvest. This is done before the rainy season as an initial management practice intended to aerate the soil and enhance water infiltration and root development. After that, a plow pass is made at a depth of about 5–10 cm using a disc to create a suitable planting bed. Planting is done from October to November, before the first effective rainfall of autumn. Nitrogen (N40) is applied with urea in the seedbed. Planting is done from October to November, before the first effective rainfall of autumn. Nitrogen (N40) is applied with urea in the seedbed.

2.2 | Experimental design

The plots were designed as a randomized complete block to assess the effectiveness of vegetative buffer strips during different growth phases along a degraded hillslope close to a wheat field. A control plot with bare soils (Figure 1a) was also studied in order to compare with the treatments of vetiver-grass (Figure 1b) and native turf-grass (Figure 1c).

A total of twelve 10 m² (1 × 10 m) experimental plots with a 15% slope were used. All of the plots (four repetitions) were isolated from the surrounding environment to the 10 cm depth using galvanized sheets (Kelarestaghi, Ahmadi, Esmaeili Ori, & Ghodusi, 2008; Lee, Isenhar, Schultz, & Mickelson, 1999). A drainage path running downslope in each plot was established to drain the outflow into 120-L containers. On the lower part, 3 m of grass were cultivated at the end of January, leaving the other 7 m bare. In Figure 2, the percentage of vegetation cover in both treatments can be observed during the monitoring period.

2.3 | Runoff simulation experiment procedures

A rainfall dataset for the years 1995–2015 was obtained from the Dasht-e-Naz weather station, located in Sari. First, we estimated the total amount of rainfall associated with different rainfall durations (10, 20, and 30 min) and different return periods (2, 5, 10, 25, 50, and 100 years) using the Abkhezr and Ghahrama model, which is highly adapted to our study area (Equation (1); Ghahraman & Abkhezr, 2004):

\[
R_{60}^{10} = e^{0.291 (R_{1440}^{2})^{0.694}} \quad AdjR^2 = 0.49, \ P<0.0001 \quad (1)
\]

where \(R_{60}^{10}\) is hourly rainfall with a 10-year return period and \(R_{1440}\) is the maximum daily rainfall.

For this study, we selected the most common extreme rainfall events associated with the study area (Sadeghi Ravesh, 2011) for the 25- and the 100-year return periods and 10-min duration. Therefore, for an experimental plot area of 10 m², runoff rates of 628 (62.8 mm hr⁻¹) and 786 L hr⁻¹ (78.6 mm hr⁻¹) for the 25- and 100-year return periods were pumped, respectively, using a relaxing basin and water retainer with an output equal to the width of the plot and upstream of the plot. A 5 cm (2-inch pump; model PTG-208, Robin-Subaru Ltd, Japan) was used to produce the desired runoff volume in each plot experiment (Figure 1d). This device is able to reach a maximum flow rate of 520 L min⁻¹ and water column height of 32 m at its top performance.

2.4 | Runoff sampling

Overland flow that crossed the buffer strips and made it across the plots was collected by tanks installed at the footslope position (Figure 1e). The experiments were repeated each month from February 2015 to January 2016 to monitor the effects of plant growth as the vegetation in the buffer strips matured. Two samples were collected from the simulated runoff: (a) one 250 ml bottle to calculate nitrate concentration; and one 1.5 L bottle to calculate soil loss and sediment concentration. The nitrate samples were stored in coolers and immediately transported to the laboratory (Lee et al., 1999). Nitrate concentration was measured in the laboratory of the Regional...
Water Office of Mazandaran Province, Iran, using ultraviolet spectrophotometry (Tudorache, Ioniță, Marin, Marin, & Badea, 2017). In this method, the nitrate absorption rate is measured at 220 nm.

To measure the total suspended sediment in the surface flow, samples were decanted, weighted, and oven dried at 105°C for 24 hr (Kavian, Azmoodeh, & Solaimani, 2014). After drying, the samples were weighed again in order to get the weight of dry total suspended sediment. The amount of suspended solids in the water samples (TSS) was calculated using Equation (2) (Lee et al., 1999).

\[
TSS = \frac{M}{V}
\]  

(2)

\(M\) represents the weight of dry particles (mg) and \(V\) means the total volume of the water in the sampling bottle (L).

The efficiency of the vegetative buffer strips in runoff pollutants removal was calculated using Equation (3) (Lee et al., 1999):

\[
\text{Effectiveness}(T_i) = \left(1 - \frac{P_i}{P_1}\right) \times 100
\]  

(3)

\(T_i\) represents the efficiency of the grass (i) for contamination removal (%), \(P_i\) is the concentration of the studied pollutant in the water from the specific treatment (i), and \(P_1\) is the concentration of the specific pollutant in the water sample from the bare soil plot.

### 2.5 Statistical analysis

Results of runoff, sediment concentration, and nitrate transported were depicted in box plots and radar graphics, respectively. After that, descriptive statistics (average, standard deviation, and maximum and minimum values) were calculated. To compare results between treatments and runoff events, a one-way ANOVA was conducted. Normality was tested using the Saphiro-Wilk test and then the Tukey test as post hoc test for the normally distributed variables was applied. All the statistical analyses were made using SigmaPlot version 13 (Systac Inc.).

### 3 RESULTS

#### 3.1 Runoff generation

Runoff results are summarized for all treatments in Table 1 and each runoff experiment and its respective runoff volume collected are depicted in Figure 3. In general, 25-year return period events generated much lower runoff volume than 100-year events. The highest average runoff volume was found for the control plots, reaching 30.5 ± 8.6 L m⁻² and 55.4 ± 7.7 L m⁻² for 25- and 100-year events, respectively. The highest maximum runoff volumes were also found in the control plots at 41.8 m⁻² (25-years) and 64.4 L m⁻² (100-years). The lowest average runoff volumes were produced in the vetiver plots at 13.4 ± 4.2 L m⁻² and 28.6 ± 11.2 L m⁻² for 25- and 100-year return periods, respectively. It was observed that the efficiency of vetiver was highest from the beginning of spring (05/15) to mid-summer (07/15). After that, runoff volume was constant. The greatest variability among plots in runoff volume was found during 03/15. The turfgrass vegetative buffer was not very effective the first month after planting and after the end of summer (09/15) its mitigation power decreased drastically for both the 25- and 100-year rainfall return periods, following a trend that was similar to the control plot.

#### 3.2 Sediment concentration

Sediment concentration results are summarized in Table 2 and its temporal evolution for the 25- and 100-year return periods is depicted in Figure 4. Sediment concentration results showed that the highest average soil erosion was produced in the control plots (62.5 ± 19.1 g L⁻¹ and 244.5 ± 91.8 g L⁻¹ for the 25- and 100-year return periods, respectively). The highest maximum soil erosion values were also found in the control plots, reaching 101.2 and 430.6 g L⁻¹ for 25- and 100-year rainfall return periods, respectively. It was observed that the efficiency of vetiver grass was not better than vetiver but demonstrated better soil erosion control than the control and turf grass treatments. Turfgrass vegetation buffer was not very effective the first month after planting and after the end of summer (09/15) its mitigation power decreased drastically for both the 25- and 100-year rainfall return periods.

**Table 1** Runoff results (L m⁻²) after conducting the runoff experiments

<table>
<thead>
<tr>
<th>Buffer strips</th>
<th>Parameters</th>
<th>25 years</th>
<th>100 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>(\bar{\pi}) x</td>
<td>30.5 ± 8.6</td>
<td>55.4 ± 7.7</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>41.8</td>
<td>64.4</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>14.8</td>
<td>34.1</td>
</tr>
<tr>
<td>Vetiver</td>
<td>(\bar{\pi}) x</td>
<td>13.4 ± 4.2</td>
<td>28.6 ± 11.2</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>24.2</td>
<td>54.8</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>8.1</td>
<td>15.7</td>
</tr>
<tr>
<td>Turf-grass</td>
<td>(\bar{\pi}) x</td>
<td>16.2 ± 5.8</td>
<td>31.3 ± 14.3</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>27.8</td>
<td>53.2</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>7.2</td>
<td>15</td>
</tr>
</tbody>
</table>

Note. \(\bar{\pi}\): total average values; Max: maximum runoff collected during a runoff experiment; Min: minimum runoff collected during a runoff experiment.
The temporal evolution of the sediment concentration values in the vetiver buffer strip plots showed that the lowest values were recorded 2 months after planting (03/15) and after the summer (09/15). Turfgrass showed a decrease in effectiveness with time since plantation for both return period events (Figure 4).

### 3.3 Nitrate concentration

The highest nitrate concentrations were found in the control plot, averaging $10.4 \pm 1.1 \text{ mg L}^{-1}$ and $37.6 \pm 8.0 \text{ mg L}^{-1}$ for the 25- and 100-year return period events, respectively. The vetiver treatments were the most effective at reducing solute transport with average nitrate concentration values of $2.9$ (25 years) and $16.4 \text{ mg L}^{-1}$ (100 years). This was lower than the turf-grass treatments, where the average values were $4.0$ and $20.9 \text{ mg L}^{-1}$ for 25- and 100-year return period events, respectively. However, the turf-grass values were lower than the control values (Figure 5; Table 3).

### 4 DISCUSSION

The application of restoration and conservation techniques to degraded hillslopes with bare soils in semiarid and arid environments has been demonstrated to be highly beneficial in this research. The highest water and soil losses and pollutant transport were recorded in the control plots with bare soils (Tables 1 and 2). These results coincide with those of other researchers working in abandoned (Kou et al., 2016; Lasanta, Nadal-Romero, & Arnáez, 2015) and over-grazed...
areas. These problems can be more intense for hillslopes that have been cultivated in the past and where herbicides and heavy machinery were used, as the hydrological and geomorphological dynamics may be changed. Also, other authors such as Kalantari, Ferreira, Walsh, Ferreira, and Destouni (2017) have reported that land degradation due to mismanagement of hillslopes with bare soils can generate problems for periurban areas in the future. Therefore, our findings about hillslopes conservation provide new insights and valuable information on the BMPs for degraded hillslopes in semiarid environments.

We confirmed that the use of grass covers such as vetiver and turf-grass are relatively easy to apply and are effective in reducing land degradation rapidly, as was also discovered by Morvan et al. (2014) and Kirchhoff, Rodrigo-Comino, Seeger, and Ries (2017) in cultivated areas. Our comparison of the vetiver and turf-grass buffer strips indicates that both of them were effective in reducing soil and water losses and pollutant transfers (Figures 3–5). This point demonstrates the novelty of this research. We demonstrated that although vetiver appeared to be slightly more effective at this than turf-grass, only one of the six comparisons had a statistically significant difference (Table 4). During the first 2 months, the turf-grass showed a

FIGURE 4  Sediment concentration (g L\(^{-1}\)) collected during the runoff simulations per month for 25 and 100-year return period rainfall events per treatment. Each box plot represents the data obtained from the four plots monitored [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 5  Nitrate concentration collected during the runoff simulations each month for 25- and 100-year return period rainfall events. Values along the radar axes are in mg L\(^{-1}\) per each runoff event [Colour figure can be viewed at wileyonlinelibrary.com]
greater efficiency in runoff pollutants removal (Figure 2) due to faster growth and consequently higher vegetation cover compared with the vetiver-grass. From the fourth month, vetiver-grass became more efficient in this, due to the increased root and stem density. This efficiency remained until almost the end of experiment period. It also should be noted that a relative drop in efficiency was observed during the vetiver-grass dormancy period. Meanwhile, the turf-grass lost its efficiency over time due to vegetation cover reduction. These results are also consistent with many other researchers that previously tested buffer strips (Borin, Passoni, Thiene, & Tempesta, 2010; Duchemin & Hogue, 2009; Hay et al., 2006; Lee et al., 2003; Mankin et al., 2007; Patty, Real, & Grill, 1997; Wang, Duggin, & Nie, 2012). We observed that the maximum efficiency of the vetiver buffer strips occurred after about 4 months, coinciding with when the vetiver-grass had reached its maximum growth and vegetation cover. Golabi et al. (2005) had similar findings, concluding that the efficiency of the vetiver-grass coincided with an increase in stem density. Osborne and Kovacic (1993), Bhattacharai, Kalita, and Patel (2009), and Stutter, Langan, and Lumsdon (2009) have also found similar results. A decrease in efficiency was noted for the vetiver strips during the last 4 months of the monitored period, possibly because the vetiver-grass was in its dormancy period.

Results from the turf-grass plots showed a trend of decreasing effectiveness by the buffer strips in preventing soil and water losses and pollutant transport after the second month and again from the seventh month until the end of the study period (Figures 3–5). This may be because the turf-grass cover grew more quickly than the vetiver but resulted in less total covered area. Visual inspections showed the turf-grass cover was not homogenous, not as tall as the vetiver-grass, and the turf-grass roots were not as completely developed as roots in the vetiver buffer strips.

As shown, the growth stage and age of the plants played an important role in the effectiveness of the vegetative buffer strips in sediment control. As Borin et al. (2010) noted and as we observed, both buffer strips showed their best performance in pollutant and soil erosion control when they had greater height and covered more of the soil surface. Borin et al. (2010) published a review of the achieved data for fields with vegetative buffer strips in Italy. They found that young vegetative buffer strips are able to reduce total runoff volume up to 33%, nitrogen loss up to 44%, and phosphorous up to 50% compared with bare areas. In contrast, mature buffer strips can reduce nitrate, nitrogen, and phosphorous up to 100% (Borin et al., 2010).

Mankin et al. (2007) confirmed that the plant species present in buffer strips can significantly affect their effectiveness. The effect of plant species and their growth stage on the efficiency of vegetative buffer strips has been investigated in general, but not in great detail. Therefore, more research needs to be conducted to evaluate the impact of the age of buffer strips and the types of plants included in them on the effectiveness of the strips in relation to other bio-ecological and hydrological parameters in the topsoil layers, such as the work of Hueso-González et al. (2014); Hueso-González, Martínez-Murillo, and Ruiz-Sinoga (2016) in Mediterranean mountains. Moreover, it would be interesting to compare these results with other research carried out with other soil erosion and pollutant control measures for hillslope restoration and conservation such as straw or chipped branches (Bhatt & Khera, 2006) and geotextiles (Davies, Fullen, & Booth, 2006) or under catchment scales (Kavian, Mohammadi, Gholami, & Rodrigo-Comino, 2018). The plant species used in buffer strips should be resistant to drastic changes in weather such as freezing or dry seasons to insure survival of the strip (Castillo, Gómez-Plaza, & Martinez-Mena M., 2003; Ruiz Sinoga & Martinez Murillo, 2009). Also, grazing can be a problem that could destroy the investment in buffer strips if it is not done with appropriate management controls.

An important final step in this research is the transmission of this information to Iranian policy makers and stakeholders (Bouma, 2014), who could include both the vetiver and turf-grass treatments in land management plans. Soil erosion, water loss, and pollutant transport are big concerns in Iran (Mohammadkhani, Ahmadi, & Jafari, 2011; Varnosfaderani et al., 2017), and research projects focused on the development of soil conservation and hillslope restoration techniques are vital. The distribution of results from studies such as this one to land managers and decision makers would help considerably improve knowledge about how including vegetative buffer strips in land management plans would impact water and soil quality in the degraded

<table>
<thead>
<tr>
<th>Buffer strips</th>
<th>Parameters</th>
<th>25 years</th>
<th>100 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Rₚ</td>
<td>10.4 ± 1.1</td>
<td>37.6 ± 8.0</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>12.6</td>
<td>50.8</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>8.7</td>
<td>21.3</td>
</tr>
<tr>
<td>Vetiver</td>
<td>Rₚ</td>
<td>2.9 ± 1.2</td>
<td>16.4 ± 7.2</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>6.5</td>
<td>29.9</td>
</tr>
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<td></td>
<td>Min</td>
<td>1.6</td>
<td>5.7</td>
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<tr>
<td>Turf-grass</td>
<td>Rₚ</td>
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<td>20.9 ± 8.6</td>
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<tr>
<td></td>
<td>Max</td>
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<td>37.1</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>1.7</td>
<td>9.1</td>
</tr>
</tbody>
</table>

Note. Rₚ: total average values; Max: maximum nitrate concentration collected during a runoff experiment; Min: minimum nitrate concentration collected during a runoff experiment.

<table>
<thead>
<tr>
<th>Runoff</th>
<th>25 years (p)</th>
<th>100 years (p)</th>
<th>Sediment concentration</th>
<th>25 years (p)</th>
<th>100 years (p)</th>
<th>Nitrate concentration</th>
<th>25 years (p)</th>
<th>100 years (p)</th>
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<tbody>
<tr>
<td>Treatment</td>
<td>p</td>
<td>p</td>
<td>p</td>
<td>p</td>
<td>p</td>
<td>p</td>
<td>p</td>
<td>p</td>
</tr>
<tr>
<td>Control vs. Vetiver</td>
<td>&lt;0.001*</td>
<td>&lt;0.001</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control vs. Turf-grass</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td></td>
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<tr>
<td>Vetiver vs. Turf-grass</td>
<td>&lt;0.186</td>
<td>&lt;0.862*</td>
<td>&lt;0.027</td>
<td>&lt;0.528</td>
<td>&lt;0.070</td>
<td>&lt;0.180</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Bold values mean significant differences.

* Saphiro-Wilks test did not pass.
areas. Future research must be focused on the increase of the plot to demonstrate to stakeholders and policy makers that these control measures can be adopted.

5 | CONCLUSION

We investigated the possible positive effect of two different vegetative buffer strips (vetiver-grass and native turf-grass) in soil erosion and pollutant transport (nitrates) on a representative degraded hillslope with bare soils in Mazandaran, Iran. In simulations of two different runoff volumes corresponding to 25- and 100-year return period rainfall events, the plots with bare soils had the highest runoff rates, sediment concentrations, and nitrate concentration. The plots with vetiver and turf-grass buffer strips both showed an ability to reduce runoff, soil losses, and runoff nitrate concentrations as compared with the control. The vetiver-grass was most effective when the plants reached maturity about 4 months after plantation. The absolute numbers for turf-grass indicated it was likely less effective than vetiver-grass at reducing runoff, soil erosion, and pollutant transport mitigation; however, only sediment concentration in the 25-year return period treatment was significantly different from the same in the vetiver treatment. The effectiveness of turf-grass rapidly decreased after the second month since its planting, which was when the plants achieved their maximum growth.

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