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APPLICATION OF VEGETATIVE BUFFER STRIPS UNDER NATURAL RAINFALL TO CONSERVE SOIL AND WATER

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Soil erosion is one of the most serious environmental issues in the world. The use of vegetative buffer strips is an effective strategy to reduce surface water pollutions as well as soil erosion. The present research has been conducted with aim to study the efficiency of buffer strips in runoff volume and sediment control using experimental plots. In this regard, twelve experimental plots with the dimensions of 1 m × 10 m were provided, and runoff samples were collected monthly to measure runoff volume and sediment. Vetiver grass and tall fescue were used as the plant species of the studied vegetative buffer strips. It was found that, vegetative buffer strips reduced the runoff volume up to 97% and sediment concentration up to 96%. Vetiver grass showed a high efficiency in runoff and sediment control; but, the maximum efficiency is achieved when this species is used along with a plant similar to the tall fescue in terms of density and uniformity. Also, periodic cutting the plants and cleaning the buffer strips can be considered as effective strategies to prevent vegetative buffer strips acting as the source of sediment.

Key words: sediment, vetiver grass, tall fescue, runoff volume, Sari

Soil erosion is one of the most serious environmental issues around the world. This problem occurs by soil exposure due to loss of vegetation cover which causes soil and water capacity reduction, pollution and eutrophication of water bodies (Morgan 1995; Hay *et al*. 2006; Keesstra *et al*. 2016; Kavian *et al.* 2017; Rodrigo-Comino *et al.* 2018). The use of vegetative buffer strips is a measure to deal with the mentioned issues (Yuan *et al*. 2009). Vegetative buffer strips include various plants such as grass, tree and shrub installed at the downstream of erodible and agricultural lands as well as river banks (Dabney 2003; Saleh *et al.* 2018). The mentioned strips are generally used for surface flows, sediment trapping, nutrient filtering and providing appropriate aquatic habitat (Yuan *et al*. 2009).

Vetiver grass (*Vetivera zizanioides*). Vetiver grass is widely used as a bioengineering technique to stabilize slopes, phytoremediation of polluted land and water, and many other environmental conservation measures (Shooshtarian & Tehranifar 2011). This plant is a fast-growing species with a height of 50–150 cm and an extent of 30 cm. The roots of vetiver grass are so branched and bulky those which penetrate up to the depths of 2–4 m in the soil; so, it is very effective for soil and water conservation (Iranian Association for Vetiver Promotion 2008). Vetiver grass is compatible with different climatic conditions, such as flooding, long-term drought, and temperatures in the range of 14 to 55ºC. Also, this plant is capable to re-grow after environmental stresses such as salinity, drought

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and etc. Tolerance of a wide range of soil acidity is another characteristic of vetiver grass as well as resistance to the herbicides and pesticides.

Tall fescue *(Festuca arundinacea)*. This plant species is able to increase the soil permeability and create the sheet flow due to the proper density and fast growth. So, the tall fescue can be considered as a suitable plant to be used in vegetative buffer strips.

Many studies have been conducted on the effect of vegetative buffer strips on runoff quality and quantity control (Norris 1993; Delgado *et al.* 1995; Lee *et al*. 2003; Patty *et al*. 1997; Golabi *et al*. 2005; Borina *et al*. 2005; Hay *et al*. 2006; Mankin *et al*. 2007; Duchemin & Hogue 2009; Borin *et al*. 2010; Milan *et al*. 2014). Some researchers have attempted to give a guideline for using the vegetative buffer strips for the water quality control. They believed that, the proximity of vegetative buffer strips to the source of contaminations may play an important role in their efficiency (Norris 1993). Hay *et al*. (2006) conducted an experimental study to evaluation of the impacts of the vegetative buffer strips on removing some pollutants generated by irrigated lands and rangelands, filter strips may not have high efficiency, because of high runoff volume, high slope and channelized flow. Investigation of hydraulic characteristics of runoff and sediment production in steep plots covered by grass has shown that, the plot covered by grass has less runoff and sediment by 14–25% and 81–95% respectively, than the plot control (Pan & Shangguan 2006). Lambrechts *et al*. 2014 studied the effect of plant and its morphology on the efficiency of vegetative buffer strips using experimental flume. They indicated the high sediment trapping potential of vegetative buffer strips after two months growing. According to the reports of the researcher above, plant growth increases sediment trapping by the vegetative buffer strips. Patty *et al.* (1997) conducted a study and stated that the grass strips with lengths of 6, 12 and 18 m were reduced the runoff volume by 87–100% and suspended solids by 44–100%. Lee *et al.* (2003) believed that a combination of various plants can enhance the effectiveness of the vegetative buffer strips for runoff pollution removal. Evaluation of the effect of a grass-tree system on filtering the runoff generated by a corn field fertilised by manure indicated that a grass strip can remove the runoff volume by 40%, suspended solids by 87%, total phosphorous by 64% and nitrate up to about 33%; while, the grass-tree strips reduced the runoff volume by 35%, suspended solids by 85%, total phosphorous by 85% and nitrate up to about 30% (Duchemin & Hogue 2009). After reviewing the data obtained from the studies on the performance of vegetative buffer strips in Italy, Borin *et al.* (2010) reported that the young buffer strips can reduce the phosphorous loss up to about 50%, nitrogen loss up to 44% and runoff volume by 33% as compared to the bare areas. Wakida *et al.* (2014) found a high correlation between the concentrations of suspended solids, phosphorus, chemical oxygen demand and turbidity, but not for total nitrogen in the Tijuana city. Campo-Bescos *et al.* (2015) believed that the installation of intense vegetative buffers in irrigated lands can improve the environmental conservation. However, it should not be considered as a main strategy; but also, it should be used as a supplementary pollution control approach along with other measures outside the field.

As many studies showed, the effectiveness of the vegetative buffer strips in runoff reduction and sediment removal; however, the impact of plant species on the efficiency of buffer strips has been less studied on plot scale.

The present study evaluated the impact of vetiver grass (*Vetivera zizanioides*) and native tall fescue (*Festuca arundinacea*) in runoff volume reduction and sediment removal using experimental plots of Sari (Iran) and the combination of these species on the efficiency of vegetative buffer strips in runoff volume reduction and sediment removal using experimental plots.

MATERIAL AND METHODS

Site description

The study site includes a part of rain-fed croplands of Miandorood (Mazandaran, Iran) where the wheat is grown. The study area is located at the eastern longitude of 53º10′ and northern latitude of 36º 33′ at the northern hemisphere (Figure 1).

Table 1 shows some characteristics of the studied site based on Dasht-e-Naz station weather data (Sadeghi Ravesh 2011).

T a b l e 1

Characteristics of the studied site

Land use	Soil texture classification (USDA)	Soil classification (USCS)	Soil type	Elevation from sea level [m]	Slope [%]	Mean annual temperature [°C]	Relative humidity [%]
Cropland (wheat)	Clay-loam	OH	Non-saline	23	15	17	77

Experimental design

The present study includes a one-year experiment. Twelve experimental plots with the dimensions of 1 m × 10 m and the slope of 15% were provided as randomized complete block design; so that, there were four treatments including vetiver grass, native tall fescue, combination of vetiver grass and native tall fescue, and bare (control) plots with three replications.

In the present study, experimental plots used those which were isolated with the intervals of 10 cm deep in the soil using galvanized sheets (Lee *et al.* 1999; Kelarestaghi *et al.* 2008) (Figure 2). Also, a path was created at the downslope of each plot to drain the outflow into a 120 L tank. The studied plants cultivated in late January and divided into two parts with the lengths of 3 m and 7 m. In 3 m part, the studied plant species were cultivated and the remaining 7 m was left as bare. The vegetation cover of the studied plants also was monitored during the experiment period (Table 2).

Runoff sampling

The runoff samples were taken from the rainfall water collected by tanks existing at downslope of each plot monthly since February 2015 until Jan-

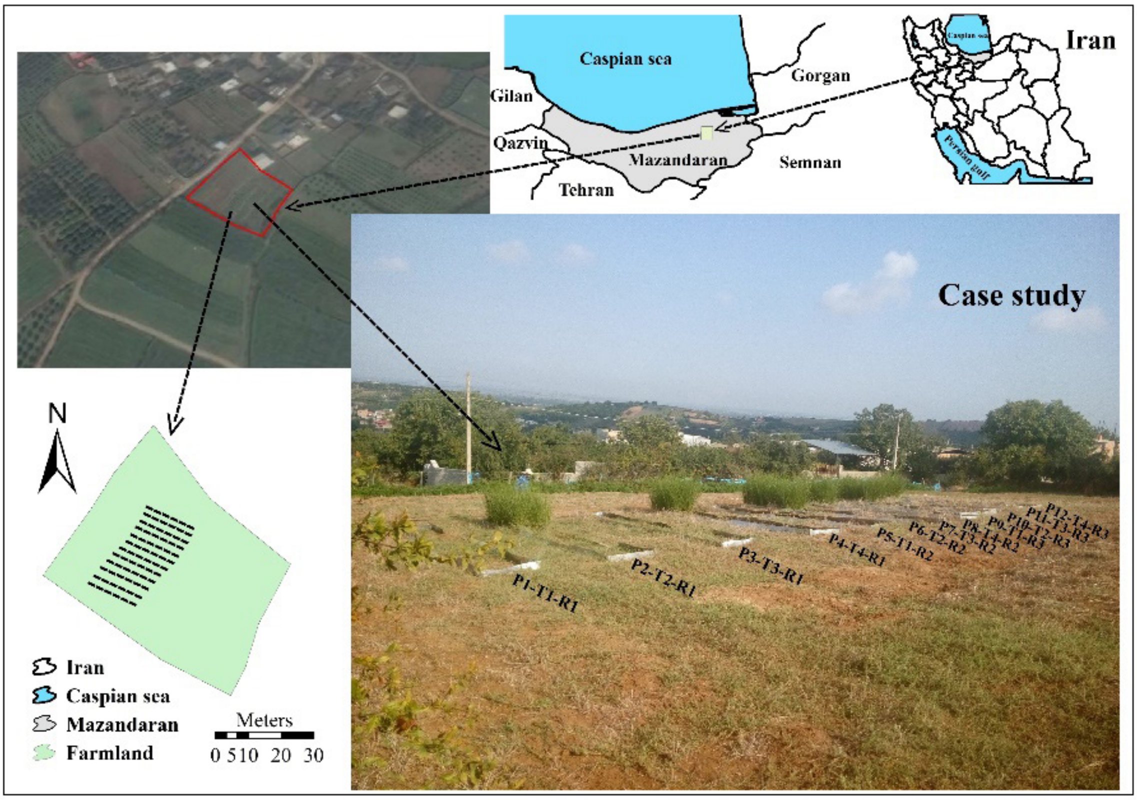

Figure 1. Location of the study area

T a b l e 2

The vegetation cover of the studied plants during the experiment period

Plant species	Feb 2015	Mar 2015	Apr 2015	May 2015	Jun 2015	Jul 2015	Aug 2015	Sep 2015	Oct 2015	Nov 2015	Dec 2015	Jan 2016
			Vegetation cover [%]									
Tall fescue	60	65	65	60	40	30	30	30	25	25	25	25
Vetiver grass	30	65	90	90	90	90	90	90	90	90	90	90

uary 2016. Before measuring the outflow volume, a 1.5 L sample was taken in order to determine sediment concentration (Lee *et al*. 1999; Kavian *et al.* 2014). Also, the amount of precipitation was measured during the experiment period using a storage rain-gauge (Table 3).

Pollutants measurement

Nitrate and phosphate concentrations were measured in the laboratory of Regional Water Office of Sari (Mazandaran, Iran). In order to measure the sediment concentration of the water samples, the samples were firstly weighted and then, were dried under temperature of 105°C in an oven for 24 hours. Finally, the samples were weighted again to obtain the weight of dry sediment. Equation (1) calculates the amount of total suspended solids of water samples (Lee *et al.* 1999; Mohammadi & Kavian 2015).

$$TSS = \frac{M}{V} \qquad \text{Equation (1)}$$

where: M is the weight of dry solids [mg] and V is the volume of water sample [L].

Determination of the efficiency of the vegetative buffer strips

Efficiency of the studied vegetative buffer strips in runoff volume reduction and sediment removal calculated using Equation (2) (Lee *et al.* 1999).

$$\text{Effectiveness } (T_1) = (1 - \frac{P_1}{P_1}) \times 100 \qquad \text{Equation (2)}$$

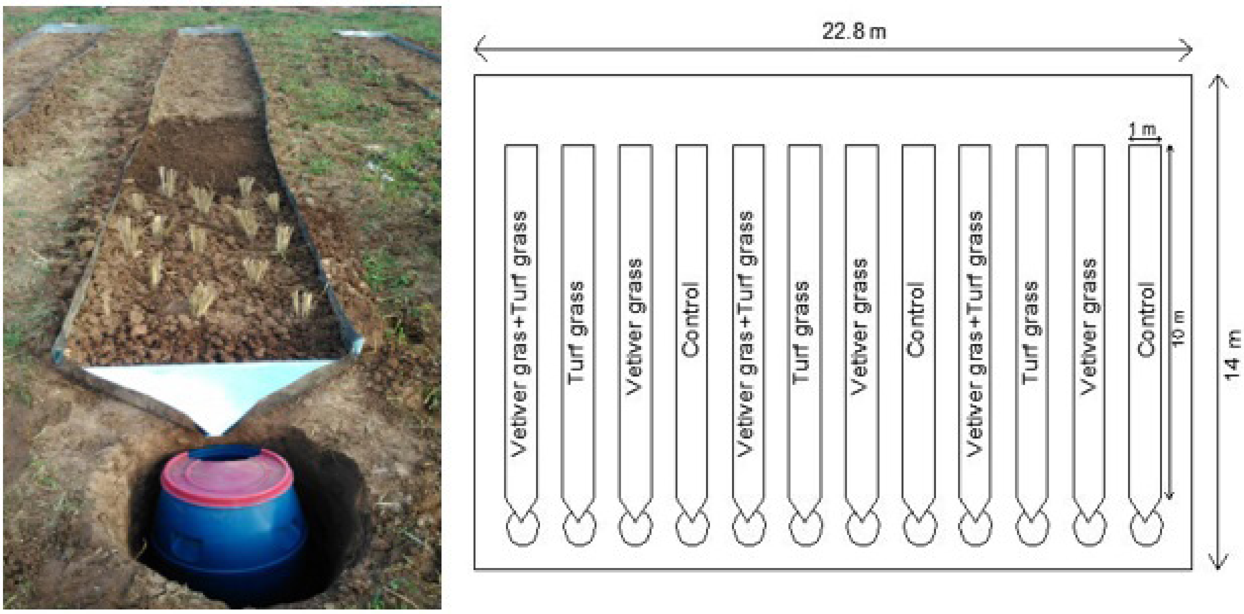

Figure 2. Installation of the experimental plots

where: T_i is the efficiency of treatment (i) [%], P_i is the value of sediment concentration (runoff volume) in the runoff sample of the treatment (i) and P_1 is the value of sediment concentration (runoff volume) in the runoff sample of the control plot.

Statistical analysis

First, a data base was provided in Excel software (2013) and then, the normality test for the data was carried out using Kolmogorov-Smirnov approach. Finally, comparison of means was con
ducted using SPSS software Version 18 to compare the performance of different treatments sediment removal and runoff volume reduction (SPSS Ink 2009).

RESULTS

Runoff volume

According to the results the treatment of tall fescue has the minimum amount of runoff volume flowing out of the experimental plots in the first and second months of the experiment with a significant difference (P = 0.01) compared to the other studied treatments. It is due to the fast growth of tall fescue and higher density compared to the vetiver grass during the mentioned period. The treatment of vetiver grass-tall fescue showed the least outflow volume since the fourth month until the 10th month. This performance is due to the growth of vetiver grass and higher soil permeability caused by the vetiver roots in the mentioned period. After the 10th month when the density of tall fescue was reduced due to climatic conditions and grazing, the treatment of vetiver grass-tall fescue had the minimum amount of runoff volume along with the treatment of the vetiver grass (Figure 3).

Figure 4 represents the best performance of runoff volume reduction for the treatment of tall fescue in the first (66%) and second (76%) months. The treatment of vetiver grass-tall fescue showed the highest efficiency compared to the other treatments

T a b l e 3

The amount of precipitation during the experiment period

Feb 2015	Mar 2015	Apr 2015	May 2015	Jun 2015	Jul 2015	Aug 2015	Sep 2015	Oct 2015	Nov 2015	Dec 2015	Jan 2016
Amount of precipitation [mm]											
19.7	23	118.8	15	5.4	3.5	83.8	3.6	112.6	112.5	100.4	55.3

T a b l e 4

Comparison of the means of sediment concentration in the four studied treatments during the experiments

Treatment	Feb 2015	Mar 2015	Apr 2015	May 2015	Jun 2015	Jul 2015	Aug 2015	Sep 2015	Oct 2015	Nov 2015	Dec 2015	Jan 2016
	Sediment concentration [g/l]*											
Control	56.35^{b}	53.61^{c}	42.51^{c}	60.55^{d}	86.29^{c}	97.30^{c}	54.13^{d}	95.00^{d}	44.83^{c}	49.07^{d}	53.63^{d}	56.97^{c}
Vetiver grass	27.61^{a}	17.69^{b}	6.38^{b}	7.27^{a}	13.81^{b}	15.57^{a}	9.74^{a}	14.25^{a}	9.41^{a}	9.81^{a}	13.41^{a}	15.38^{a}
Tall fescue	20.29^{a}	5.90^{a}	5.10^{ab}	9.69^{c}	18.12^{b}	27.24^{b}	21.65^{c}	37.05^{c}	21.97^{b}	27.48^{c}	30.03^{c}	34.18^{b}
Vetiver grass-tall fescue	25.36^{a}	13.94^{b}	2.13^{a}	2.42^{b}	4.31^{a}	22.38^{ab}	15.70^{b}	25.65^{b}	17.04^{b}	16.68^{b}	21.45^{b}	23.93^{b}

*Means followed by the same letter do not differ statistically

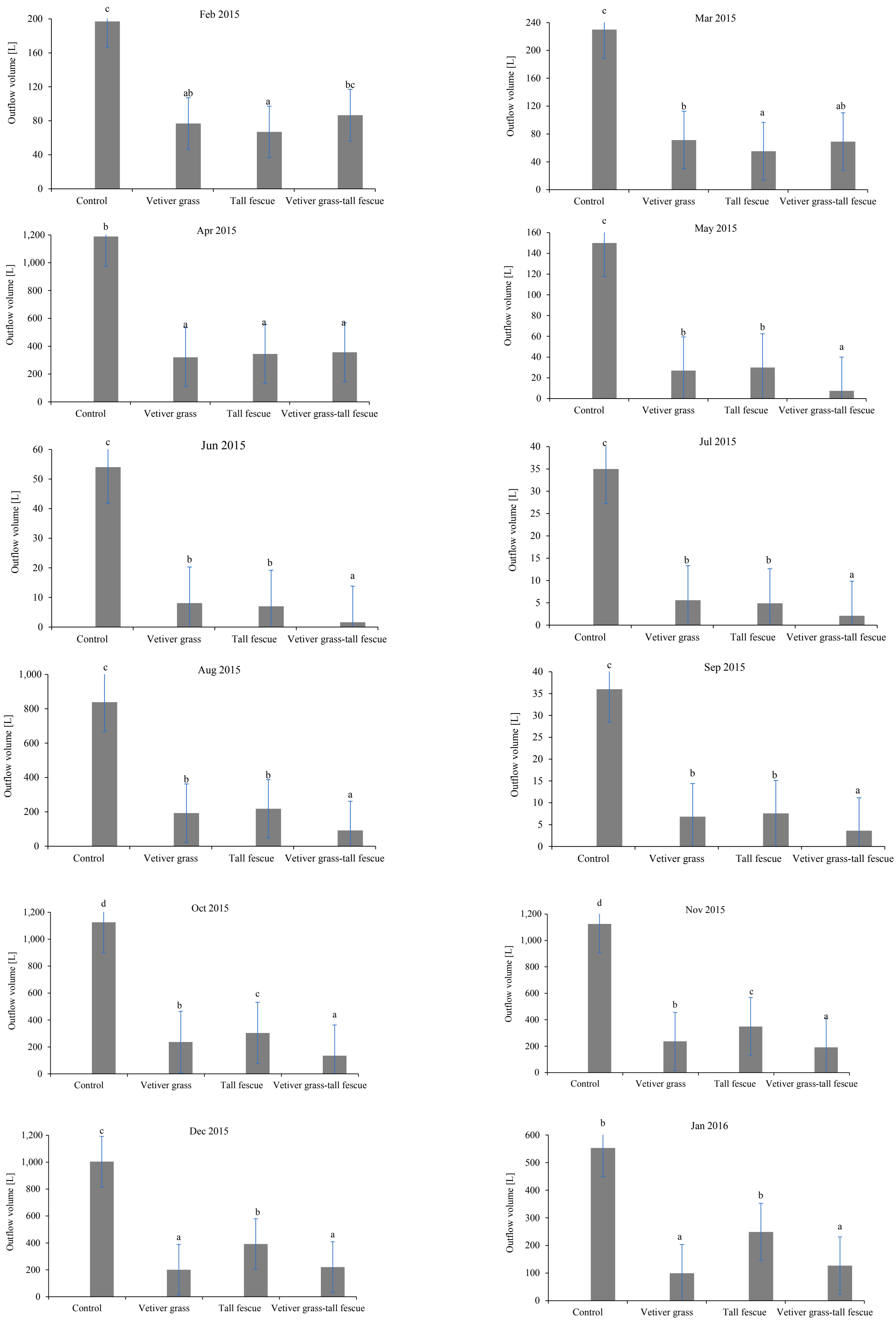

Figure 3. Variations of mean outflow volume in the four studied treatments during the experiment (Means followed by the same letter do not differ statistically)

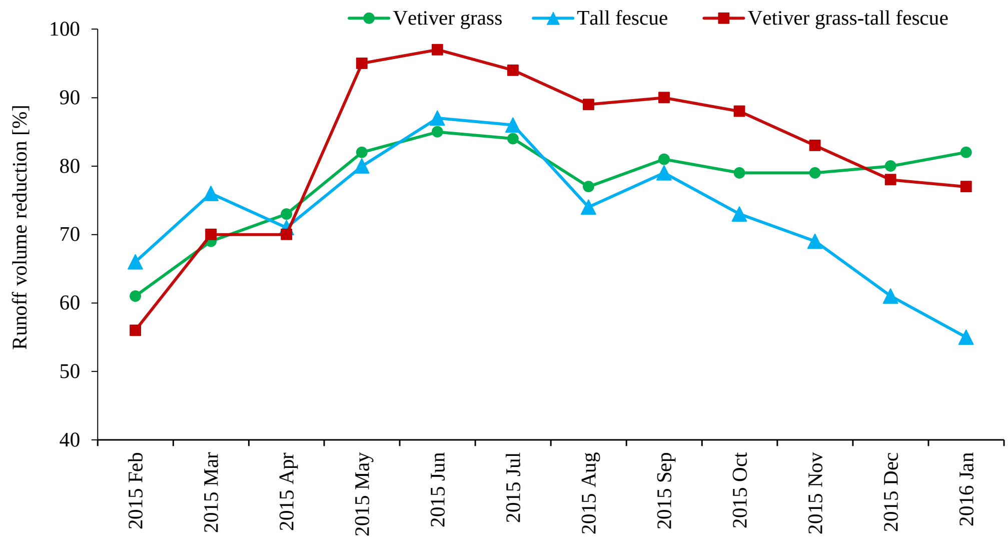

Figure 4. Variations of the efficiency of the studied vegetative buffer strips in runoff volume reduction during the experiment

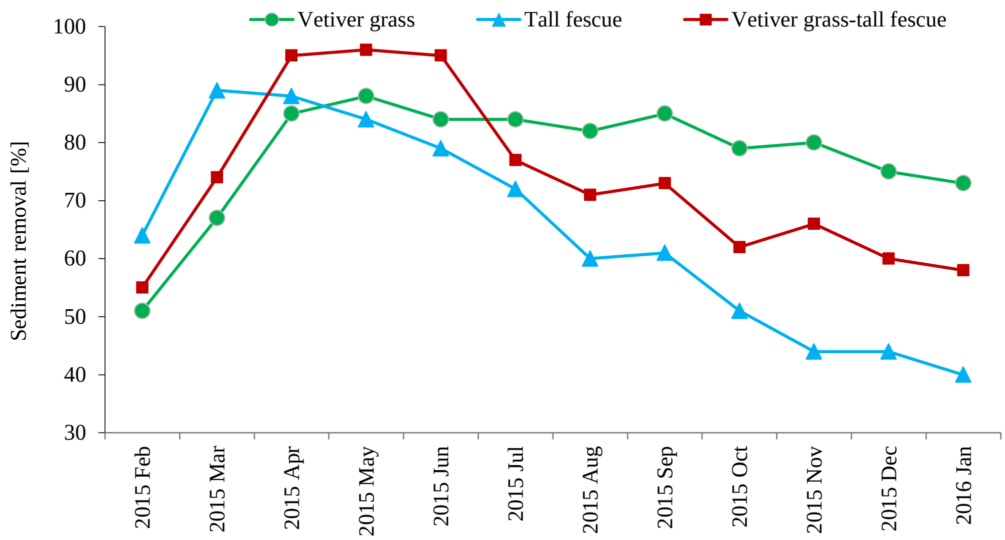

Figure 5. Variations of the efficiency of the studied vegetative buffer strips in sediment removal during the experiment

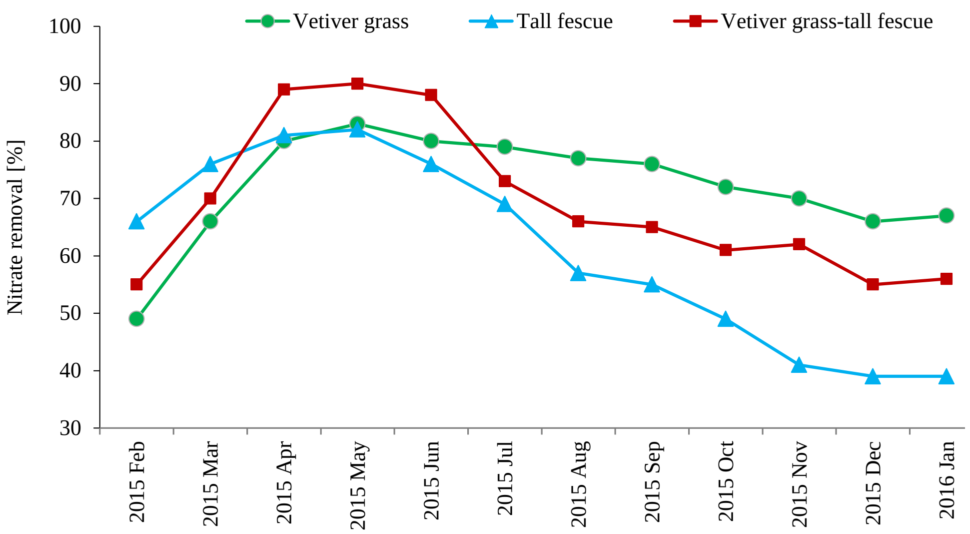

Figure 6. Variations of the efficiency of the studied vegetative buffer strips in nitrate removal during the experiment

since the fourth month until the 10th month of the experiment. Moreover, the best efficiency was obtained in the 11th and 12th months for the treatment of vetiver grass. As it is observed, the highest efficiency (97%) was found for the treatment of vetiver grass-tall fescue in the fifth month.

Sediment concentration

After some fluctuations, the treatment of vetiver grass showed the minimum amount of sediment concentration with a significant difference ($P = 0.01$) compared to the other treatments since the sixth month until the end of the experiment (Table 4). The main reasons include the ability of vetiver grass for sediment removal and its compatibility with different climatic conditions, as well as the vulnerability of tall fescue.

As Figure 5 shows, the maximum efficiency in the first and second months was observed for the treatment of tall fescue; while the treatment of vetiver grass-tall fescue had more appropriate performance than the other treatments in the third, fourth and fifth months. Since the sixth month of the experiment, the treatment of vetiver grass showed the best efficiency of sediment removal until the end of the experiment. The highest efficiency (96%) during the experiment period was also related to the treatment of vetiver grass-tall fescue in the fourth month.

Nitrate

According to Figure 6, the maximum efficiency (90%) in nitrate removal was found in the fourth month of the experiment for the treatment of vetiver grass-tall fescue. But, the treatment of vetiver grass showed the best performance since the sixth month until the end of the experiment.

Phosphate

As the results indicate, the best function of phosphate removal was determined in the third month by the treatment of vetiver grass-tall fescue. Since the sixth month of the experiment, the highest efficiency was obtained by the treatment of vetiver grass until the end of the experiment (Figure 7).

DISCUSSION

According to the results (Figure 4), the treatment of tall fescue has had the maximum runoff reduction in the first and second months of the experiment which is consistent with Owino *et al.* (2006) and Yuan *et al.* (2009). Since the third month when the tall fescue and vetiver grass had their maximum vegetation cover, the treatment of vetiver grass-tall fescue showed the minimum outflow volume. The maximum efficiency of the buffer strips in qualitative

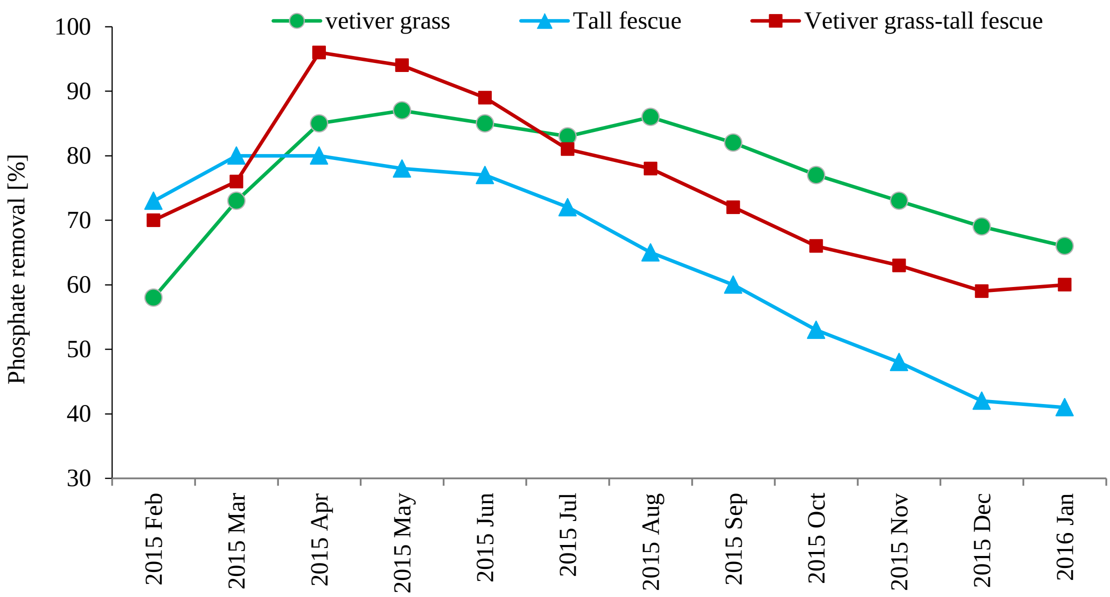

Figure 7. Variations of the efficiency of the studied vegetative buffer strips in phosphate removal during the experiment

and quantitative control of the runoff occurs when the flow passes through the strips as a sheet (Hussein *et al*. 2007). So, the highest efficiency in the runoff volume reduction was found for the treatment of vetiver grass-tall fescue because the runoff reached to the vetiver grass strip as a sheet flow after passing through the tall fescue strip. Hence, the flow was not concentrated among the bushes of vetiver grass; so, the strip of vetiver grass could present its capability to increase soil permeability. Lee *et al*. (2003) also obtained the same result which explains the proper performance of the combined vegetative buffer strips to control runoff volume and pollutants. In the last two months of the experiment, the vegetation cover of tall fescue was reduced because of changing the climatic conditions as well as grazing over the time. Therefore, the efficiency of tall fescue strip dropped while the vegetative strip kept its high efficiency in runoff volume reduction because of strong root system, higher biomass as well as compatibility to various climatic conditions. This result is consistent with Mankin *et al*. (2007) and Golabi *et al*. (2005).

Investigating the results of sediment concentration (Figure 5) represented that, the combination of vetiver grass and tall fescue can give a high efficiency in sediment removal. But, when the vegetation cover of tall fescue reduced (since the sixth month), the treatment of vetiver grass showed the highest efficiency of sediment removal compared to the other treatments until the end of the experiment. The high performance of vetiver grass is due to high resistance in various seasons and climatic conditions as well as dormancy in cold season. So, vegetation cover reduction is prevented. The achieved results are consistent with Golabi *et al*. (2005), Pan & Shanggun (2006) and Stutter *et al*. (2009).

By approaching the end of experiment, the mean concentration of sediment was higher than the early months of the experiment. This happening can be related to the sediment accumulation in the vegetative strips over time. Therefore, the vegetative buffer strips can play role as the source of sediment. Osborne & Kovacic (1993), Bhattarai *et al*. (2009) and Stutter *et al*. (2009) also obtained the same result.

The results of nitrate and phosphate (Figure 6 and 7) also represent proper function for vetiver grass-tall fescue when the mentioned plants have their maximum growth and vegetation cover. While, the treatment of vetiver grass showed higher stability than the composed buffer strip for nitrate removal due to higher resistance against grazing and climatic condition changes. This result is consistent with Matteo *et al.* (2006) and Lee *et al.* (2003). The achieved results for nitrate and phosphate are almost same as the sediment; because, the nutrients are attached to the sediment particles and transferred (Barling 1994).

CONCLUSIONS

The plots with vetiver and tall fescue buffer strips both were able to reduce runoff, sediment, nitrate and phosphate concentrations as compared to the control. But, the vetiver grass was more effective than other treatments when the plants reached maturity. Also, tall fescue showed less effective than vetiver grass at reducing in runoff, pollutant transport and soil erosion. Because, the effectiveness of tall fescue sharply decreased after the second month since planting. Therefore, the appropriate effectiveness of vetiver grass-tall fescue treatment reduced after a short time. Hence, a more appropriate efficiency for water and soil conservation will be achieved if a plant species with a density and uniformity like the tall fescue being resistant and compatible to the climatic conditions of the considered region is used along with vetiver grass in the vegetative buffer strips. The results of this study showed that the vegetative buffer strips can also act as a source of nutrients and sediment. So, periodic plants cutting and dredging of buffer strips is recommended as an effective strategy to deal with this problem. In addition, doing researches on the width of the strips, the impact of length and shape of the sub/catchment above the strip, rainfall intensity and soil moisture on the efficiency of the vegetative buffer strips can be helpful to enhance the impact of these strips in the water and soil conservation in different watersheds.

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