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ORIGINAL PAPER

The efficiency of vegetative buffer strips in runoff quality and quantity control

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Abstract In recent years, nonpoint source pollutions, caused mostly by surface runoff, have become a subject of interest. Vegetative buffer strips contain a special plant species being passed by the flow before getting into the water bodies. The main aim of the present study is to evaluate the impact of three different types of vegetative buffer strips to reduce the surface water pollutants including sediment, nitrate and phosphate. The experiments were carried out using the experimental plots with the dimension of 1×10 m^2 as well as the artificial runoff with a flow rate of 1.65 L s^{-1} during a year. The results of this study showed that the vegetative buffer strips reduced the runoff volume by 35–90%, sediment concentration by 42–94%, nitrate concentration by 35–88% and phosphate concentration by 28–95%. According to the results, the vetiver grass has a high efficiency in runoff pollutants control; but, due to the probability of creating the concentrated flow among the bushes of vetiver grass, it is strongly recommended to use a resistant plant with a density and uniformity similar to the turf grass and consistent to climatic conditions of the study area along with the vetiver grass. Also, periodic cutting the plants is as an effective strategy to deal with the role of vegetative buffer strips as a source of nutrients and sediment.

Keywords Experimental plots · Nitrate · Phosphate · Sediment concentration · Vetiver grass

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Introduction

In recent years, nonpoint source pollutions have been increasingly recognized as the major contributor causing to decline aquatic environment and river water quality (Chimwanza et al. 2006; Hong et al. 2012; Abdollahi et al. 2017). Imandoust and Gadam (2007) reported that the people are willing to pay about $1 per family per month for the water quality in Indian rivers. BMPs[1] is a common approach to eliminate destructive impacts of the surface runoff. Cheng et al. (2011) reported that the cultivated wetlands usually had a higher nutrients removal rates than the unplanted over their study period. The application of vegetative buffer strips is an effective strategy of BMPs to remove the surface water pollutions (Lam et al. 2011). A buffer strips is defined as a strip containing different plant species such as grass, tree, shrub or a combination of them that is installed at the downstream of erodible and farming lands, as well as river banks (Dabney 2003). In other word, VBSs[2] contain a special plant species being passed by the flow before getting into the water bodies, and it causes to reduce the runoff volume, accumulated pesticides and other contaminants by infiltration, absorption and sedimentation (Otto et al. 2012). Vetiver grass is a tropical plant at the south and southeast of Asia that is naturally grown in the low and high lands and various types of the soil. This plant can live in most of climates. 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 and 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.

[1] Best Management Practices.
[2] Vegetative Buffer Strips.

They believed that, the proximity of vegetative buffer strips to the source of contaminations may play an important role in their efficiency. In addition, they believe the worthiness of buffer strips not only for their usefulness in water quality control, but also, in their utility for maintenance of a large area of natural plants (Norris 1993). Otto et al. (2008) studied the effect of full-grown vegetative buffer strips on the herbicide runoff. They reported that the runoff concentration and volume are directly related to the characteristics of the rainfall event, buffer, source of the pollutants and time after the application. Some other researchers also reported that the vegetative buffer strips are able to remove the pollutants generated by agricultural activities as well as nonpoint source pollutions (Delgado et al. 1995; Lee et al. 2003; Patty et al. 1997). 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%, suspended solids by 44–100% and phosphorous by 22–89%. Lee et al. (2003) believe that a combination of various plants can enhance the effectiveness of the vegetative buffer strips for runoff pollution removal, while Hay et al. (2006) conducted an experimental study to evaluate the impacts of the vegetative buffer strips on removing some pollutants, such as, sediment, nutrients and microorganisms generated by irrigated lands and rangelands. They reported that the used filter strip did not have high efficiency, because of high runoff volume, high slope and channelized flow. Borina et al. (2005) showed that the runoff that does not pass through a vegetative buffer strip, is more affected by the total rainfall than the rainfall intensity, while the rainfall intensity plays an important role for the runoff that passes vegetative buffer strip in comparison with the total rainfall. Golabi et al. (2005) reported that the vetiver systems not only are effective in erosion control, but also, they can improve runoff quality. Mankin et al. (2007) believed that the plant species used in a buffer strip has a considerable impact on the pollutants removal. Duchemin and Hogue (2009) evaluated the effect of a grass–tree system on filtering the runoff generated by a corn field fertilized by manure. They 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%. Borin et al. (2010) reviewed the data obtained from the studies conducted on the performance of vegetative buffer strips during the recent decades in Italy. They reported that the young buffer strips can reduce the runoff volume by 33%, nitrogen loss up to 44% and phosphorous loss up to about 50% as compared to the bare areas. Moreover, they believed that a mature buffer strip is able to reduce nitrate and nitrogen concentration up to 100%. Some other researchers stated that the retention efficiency of the vegetative buffer strips is highly affected by uniformity of the vegetation cover, particularly at the beginning of their planting (Milan et al. 2014). Wakida et al. (2014) evaluated the relationship between the suspended solids and other pollutants in stormwater runoff in the Tijuana city. They found a high correlation between the concentrations of suspended solids and chemical oxygen demand, phosphorus, and turbidity, but not for total nitrogen. Campo-Bescos et al. (2015) also believed that installing the intense vegetative buffers in irrigated lands of vulnerable areas can be effective in environmental conservation and they may reduce the destructive agricultural impacts. However, it should not be considered as an alternative strategy, but also, it should be used as a supplementary pollution control approach along with other measures outside the field. Dindaroglu et al. (2015) conducted a study to determine the appropriate width of riparian buffer strips using a hydro-ecological approach for providing the soil and water conservation. Lack of experimental evidence about buffers with 1–10m width has made it difficult to present the definitive conclusions about the efficiency of the vegetative buffers in agricultural regions.

As can be found in the conducted studies, the efficiency of the vegetative buffer strips in removal of the surface water pollution is obvious; however, plant species and type of contaminants have considerable impact on the efficiency of VBSs. The main aim of this study is to evaluate the impact of vetiver grass (*zizanioides vetivera)* and native turf grass (*festuca arundinacea)* of Sari (Iran) and the combination of these species on the efficiency of vegetative buffer strips in removal of the surface water pollutions. The experimental activities were carried out from Feb 2015 to Jan 2016 in Sari, Mazandaran, Iran.

Materials and methods

Site description

The study area includes a part of rain-fed farming lands (Kavian et al. 2017) of Miandorood (Sari, Iran) located at the eastern latitude of 53°10′ and northern latitude of 36°33′ in the northern hemisphere (Fig. 1). Elevation from sea level is 23 m, the hill slope is 15% with a north–south geographical direction and clay-loam soil texture. According to the Dasht-e Naz station meteorological data, mean annual precipitation, temperature and relative humidity of the study area are 789 mm, 17 °C and 77%, respectively (Sadeghi Ravesh 2011; Kavian et al. 2014).

Experimental design

Experimental plots in a randomized complete block design were used to evaluate the retention efficiency of the vegetative buffer strips with various plant species and growth stages in removing different types of the pollutants existing in the runoff. The studied treatments were as follows:

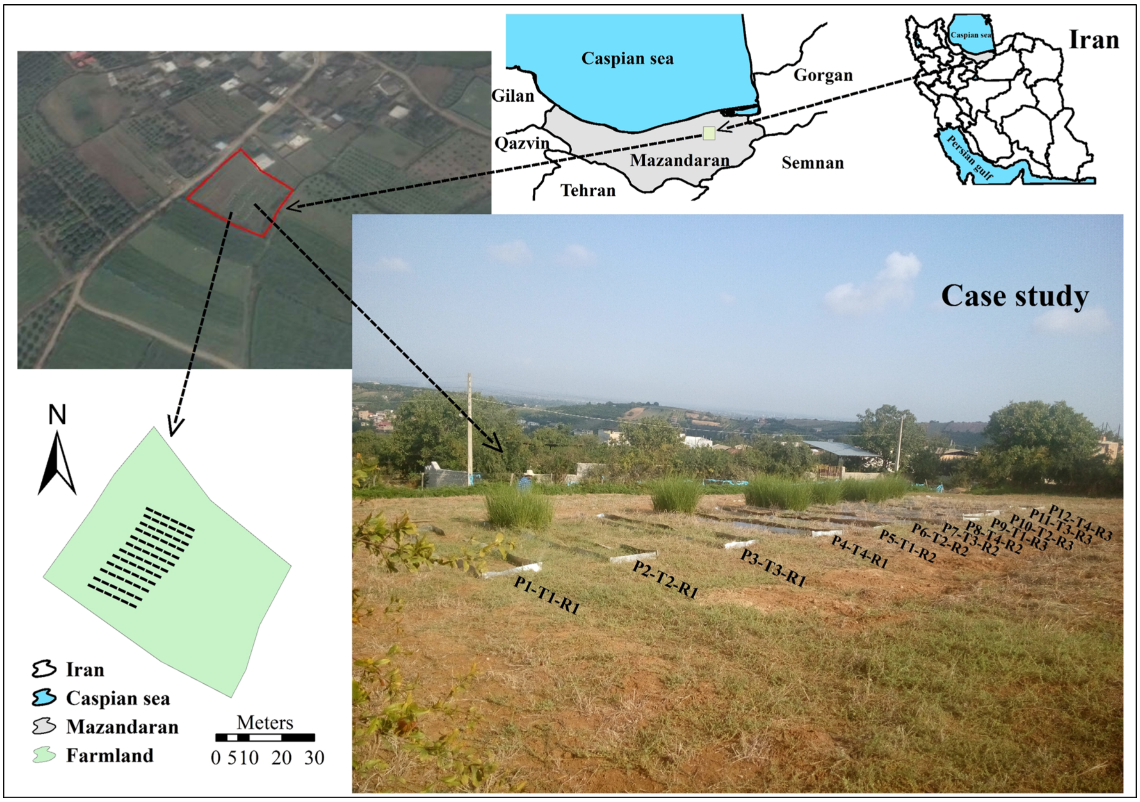

Fig. 1 Location of the study area

Treatment 1: Vetiver grass, treatment 2: native turf grass, treatment 3: combination of vetiver grass and native turf grass, treatment 4: bare (control).

In the present study, experimental plots with the area of 10 m^2 (1 m × 10 m) and the slope of 15% were used and they were isolated with the intervals of 10 cm deep in the soil using galvanized sheets (Lee et al. 1999; Kelarestaghi et al. 2008; Mohammadi and Kavian 2015). At the downslope of each plot, a path was created to drain the outflow into a 120-L tank. Also, the studied plants were cultivated in late January and divided into two parts with the lengths of 3 and 7 m. In 3 m part, the studied plant species were cultivated and the remaining 7 m was left as bare (Fig. 2).

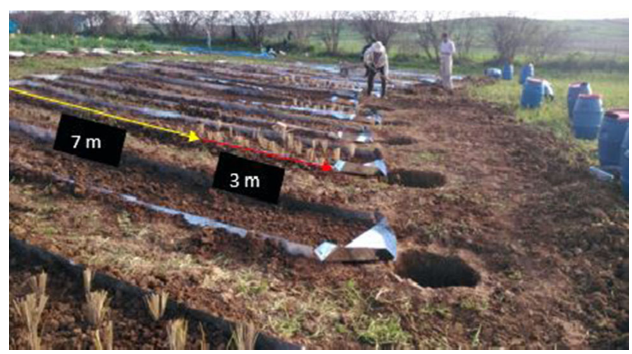

Fig. 2 Preparation of experimental plots

Studied plants

Vetiver grass (zizanioides vetivera)

(Vetiver grass is a fast-growing species with a height of 50–150 cm and an extent of 30 cm. Vetiver roots are so branched and bulky which penetrate up to the depths of 2–4 m in the soil that is very effective for soil and water conservation (Iranian Association for Vetiver Promotion 2008). This plant is currently used as a bioengineering technique for slope stabilization, phytoremediation of polluted land and water, and other environmental conservation measures (Shooshtarian and Tehranifar 2011). Some physiological characteristics of vetiver grass are as follows:

Compatibility with different climatic conditions, such as long-term drought, flooding, and temperatures in the range of 14–55 °C.

The ability to regrow after environmental stresses such as drought and cold salinity.

Tolerant of a wide range of soil acidity (3.3–12.5)

Resistant to the herbicides and pesticides

High efficiency to absorb dissolved nutrients such as nitrate, phosphate as well as heavy metals in contaminated water

Table 1 Vegetation cover percentage of the studied plants during the experiments

Month	Vegetation cover (percent)											
Plant	Feb 2015	Mar 2015	Apr 2015	May 2015	Jun 2015	Jul 2015	Aug 2015	Sep 2015	Oct 2015	Nov 2015	Dec 2015	Jan 2016
Vetiver grass	30	65	90	90	90	90	90	90	90	90	90	90
Turf grass	60	65	65	60	40	30	30	30	25	25	25	25

Turf grass (festuca arundinacea)

Proper density and fast growth of turf grass make this plant able to increase the soil permeability and create the sheet flow. So, the turf grass can be considered as a suitable plant to be used in vegetative buffer strips.

Runoff sampling

The samples were taken from the runoff collected by tanks existing at downslope of each plot monthly since February 2015 until January 2016.

The artificial runoff was generated using a pump with a flow rate of 1.65 L s^{-1}. Two separate samples were taken from the collected runoff in order to enhance the accuracy of the pollutant measurements. One of the samples was taken by a 250-mL container to measure nitrate and phosphate concentration, and another sample was taken using a 1.5 L container to measure sediment concentration. The samples with the volume of 250 ml were placed in coolers and were immediately transferred to the laboratory (Lee et al. 1999; Safari et al. 2016).

Vegetation cover

Vegetation cover was measured monthly for its probable impact on the efficiency of vegetative buffer strips. Table (1) shows the variations of vegetation cover percentage for the two studied plants during the experiments.

Pollutant measurements

The amounts of nitrate and phosphate were measured in the laboratory of Regional Water Office of Sari, Mazandaran, Iran. In addition, in order to measure the amount of sediment in the water samples, the samples were firstly weighted and, they were then dried in an oven under the temperature of 105 °C for 24 h. Finally, the samples were weighted again to obtain the weight of remaining sediment. Equation (1) calculates the amount of TSS[3] (Lee et al. 1999) which is one of the main pollutants because of their correlation with other pollutants of the water sample (Wakida et al. 2014).

$$\mathrm{TSS} = \frac{M}{V} \quad (1)$$

where M is the weight of solids after drying the water sample (mg) and V is the volume of water sample (L).

Calculation of the efficiency of the vegetative buffer strips in runoff pollutions removal

Efficiency of the studied vegetative buffer strips in removing the considered runoff pollutants was calculated using Eq. (2) (Lee et al. 1999), as follows:

$$\text{Effectiveness } (T_i) = \left(1 - \frac{P_i}{P_1}\right) \times 100 \quad (2)$$

where T_i is the efficiency of treatment (i) in the considered pollutant removal (%), P_i is the concentration of the considered pollutant in the runoff sample of the treatment (i) and P_1 is the concentration of the considered pollutant in the runoff sample of the control plot.

Statistical analysis

To compare the performance of different treatments in removing the studied pollutants, a data base was created in Excel software (2013) and then, the normality test for the data was carried out using Kolmogorov–Smirnov approach. Also, comparison of means was conducted using SPSS software Version 18 (SPSS Ink 2009).

Results and discussion

Runoff volume

The results showed that the treatment of turf grass has the minimum amount of runoff volume flowing out of the experimental plots during the first and second months of the experiment with a significant difference ($P = 0.01$) from the

[3] Total Suspended Solids.

other studied treatments to the reason is the fast growth of this plant and higher density as compared with the vetiver grass during the first and second months. Since the third month until the 8 month, the treatment of vetiver grass–turf grass showed the least runoff volume. This performance is also due to the growth of vetiver grass and higher soil permeability caused by the vetiver roots. After the eighth month, when the density of turf grass was reduced due to climatic conditions and grazing, also the treatment of vetiver grass–turf grass along with the treatment of the vetiver grass had the minimum amount of runoff volume (Table 2).

Sediment concentration

Statistical analysis of the results indicated that the treatments of vetiver grass–turf grass and vetiver grass had the minimum amount of sediment concentration since the third month until the eighth month with a significant difference ($P = 0.01$) from the rest of studied treatments, while the treatment of vetiver grass had the minimum sediment concentration from the ninth month to the end of the experiment (Fig. 3). 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 turf grass.

Nitrate

Comparison of means for the nitrate concentration indicated that the studied treatments had no significant difference in the first, second and fourth months. The reason is the nitrate dissolving in the water. In the third and fifth months, the treatment of vetiver grass–turf grass, and in the sixth, seventh and eighth months, the treatment of vetiver grass as well as the treatment of vetiver grass–turf grass showed the minimum amount of nitrate concentration with a significant difference ($P = 0.01$) from the other treatments. Furthermore, the treatment of vetiver grass had the minimum amount of nitrate concentration from the ninth month to the end of the experiments (Fig. 4). Some results are similar to the results of sediment concentration. Therefore, it can be found that the nitrate and sediment concentrations are correlated, because, the nutrients are attached to the fine sediments. This result has been also obtained by Barling (1994).

Phosphate

According to the results of phosphate measurement (Table 3), it was found that there was no significant difference among the studied treatments for the amount of phosphate concentration in the first and second months of the experiment; whereas, in the third, fourth and fifth months, the minimum phosphate concentration was related to the treatment of vetiver grass–turf grass. The reason is same as the nitrate concentration. In addition, in the last 3 months of the experiments, the treatment of vetiver grass showed the minimum amount of phosphate concentration with a significant difference ($P = 0.01$) from the other studied treatments. It is probably due to high rate of the phosphate absorption by vetiver grass, but not for the turf grass.

Retention efficiency of vegetative buffer strips

In this section, the efficiency of different studied treatments in reducing the sediment concentration has been investigated and determined based on the control plot.

Runoff

Figure (5) indicates the minimum reduction in the runoff volume for the control plot. Also, the best performance for the reduction in the runoff volume was observed in the first second, sixth and eighth months for the treatment of turf grass.

The treatment of vetiver grass–turf grass showed the highest efficiency in the third, fourth, fifth, seventh, ninth and the last months. Moreover, the best performance was obtained in the tenth and eleventh months for the treatment of vetiver grass. As it is observed, the best efficiency is for the treatment of vetiver grass–turf grass in the fourth month.

About the reduction in the runoff volume, the results showed more appropriate performance for the treatment of turf grass in the first 2 months after planting; but the treatment of vetiver grass–turf grass showed an appropriate performance to reduce the runoff volume since the third month until the eighth month with an insignificant difference from the treatment of turf grass. Since the maximum efficiency of the buffer strips in qualitative and quantitative control of the runoff occurs when the flow passes through the strips as a sheet (Hussein et al. 2007); therefore, the maximum efficiency in the runoff volume reduction was found for the treatment of vetiver grass–turf grass; because, the flow reached to the vetiver grass strip as a sheet flow after passing through the turf grass strip. Therefore, the creation of concentrated flow among the bushes of the vetiver grass was prevented and therefore, the vetiver grass strip could show its ability to increase the soil permeability. The mentioned result is consistent with Lee et al. (2003)'s results. Since the ninth month, the treatment of turf grass had a sharp drop in runoff volume reduction which can be due to the cold weather and existing inappropriate conditions for the plant growth and reduction in the plant density in the studied area. The treatment of vetiver grass–turf grass also showed a relative drop in the same month with the same reason as mentioned before, so that the treatment of vetiver grass surpassed other treatments in the runoff volume reduction and showed the highest efficiency, while

Table 2 Comparison of means of runoff volume flowing over the plots in four studied treatments during the experiments

Treatment	Outflow volume (L)											
	Feb 2015	Mar 2015	Apr 2015	May 2015	Jun 2015	Jul 2015	Aug 2015	Sep 2015	Oct 2015	Nov 2015	Dec 2015	Jan 2016
Control	342^{c}	363^{d}	376^{c}	320^{d}	283^{d}	213^{c}	323^{d}	335^{c}	364^{b}	335^{c}	377^{c}	336^{c}
Vetiver grass	319^{ab}	286^{c}	194^{b}	130^{c}	140^{c}	97^{b}	119^{c}	143^{b}	128^{a}	150^{a}	163^{a}	187^{a}
Turf grass	310^{a}	118^{a}	77^{a}	42^{b}	50^{b}	44^{a}	70^{b}	60^{a}	230^{b}	277^{b}	306^{b}	307^{b}
Vetiver grass–Turf grass	336^{bc}	215^{b}	67^{a}	26^{a}	35^{a}	46^{a}	46^{a}	67^{a}	101^{a}	161^{a}	193^{a}	178^{a}

Means followed by the same letter do not differ statistically

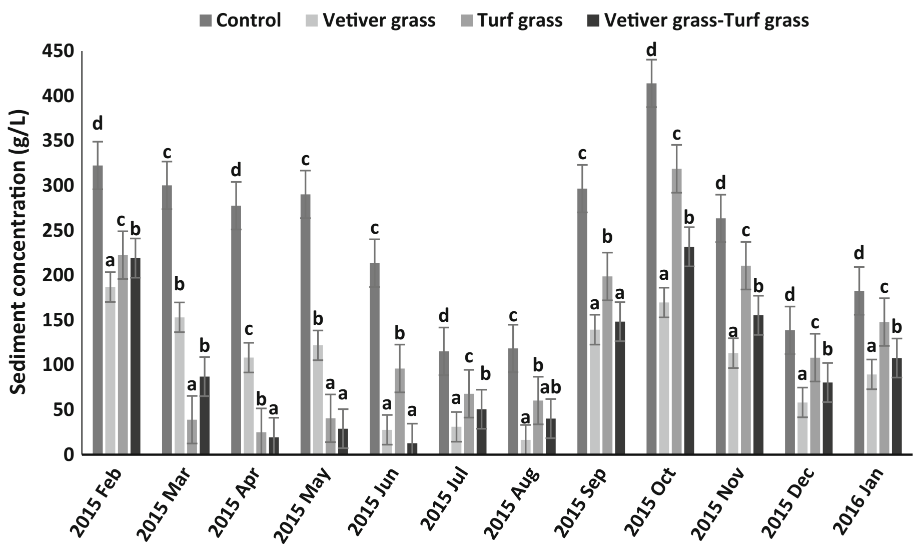

Fig. 3 Variations of mean sediment concentration in the four studied treatments during the experiment (Means followed by the same letter do not differ statistically)

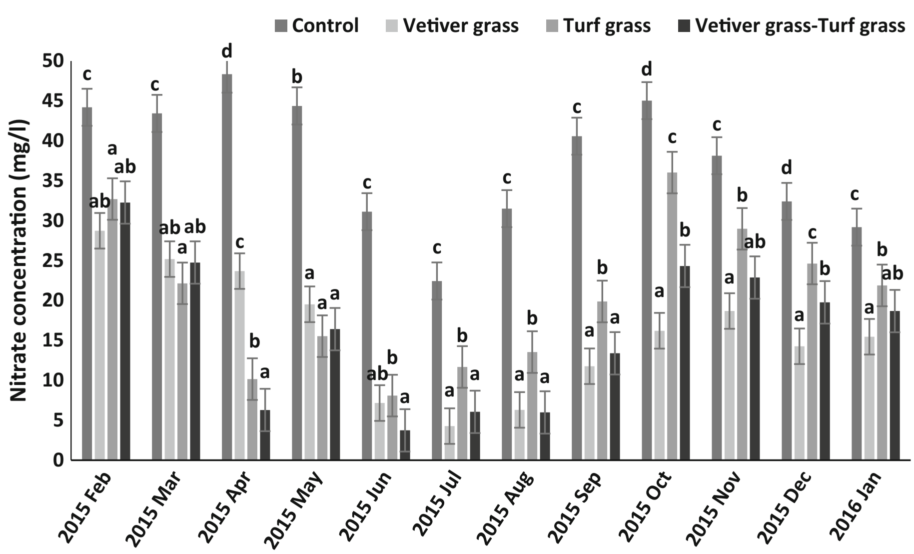

Fig. 4 Variations of mean nitrate concentration in the four studied treatments during the experiment (Means followed by the same letter do not differ statistically)

it had an ascending trend until the sixth month and a constant trend after that. It is due to high resistance and adaptability of vetiver grass to the various climates and seasons as well as its dormancy in the cold season that cause to prevent the plant density reduction. It should be noted that the treatment of vetiver grass–turf grass had still a more appropriate performance as compared with the treatment of vetiver grass in the same period. All studied treatments presented a considerable efficiency drop in the runoff volume reduction which it can be due to increasing

Table 3 Comparison of means of phosphate concentration in the four studied treatments during the experiment

Treatment	Phosphate concentration (mg/L)											
	Feb 2015	Mar 2015	Apr 2015	May 2015	Jun 2015	Jul 2015	Aug 2015	Sep 2015	Oct 2015	Nov 2015	Dec 2015	Jan 2016
Control	1.30[b]	1.19[b]	1.49[c]	0.90[c]	0.88[c]	0.54[b]	0.63[c]	0.72[b]	0.86[c]	0.69[c]	0.56[c]	0.52[c]
Vetiver grass	0.94[a]	0.58[a]	0.49[b]	0.24[b]	0.18[ab]	0.06[a]	0.04[a]	0.32[a]	0.33[a]	0.30[a]	0.22[a]	0.24[a]
Turf grass	1.05[a]	0.52[a]	0.55[b]	0.32[b]	0.26[b]	0.25[a]	0.30[b]	0.46[a]	0.60[b]	0.50[b]	0.40[b]	0.41[b]
Vetiver grass–Turf grass	1.01[a]	0.44[a]	0.07[a]	0.07[a]	0.11[a]	0.10[a]	0.17[ab]	0.32[a]	0.30[a]	0.35[a]	0.30[ab]	0.31[ab]

Means followed by the same letter do not differ statistically

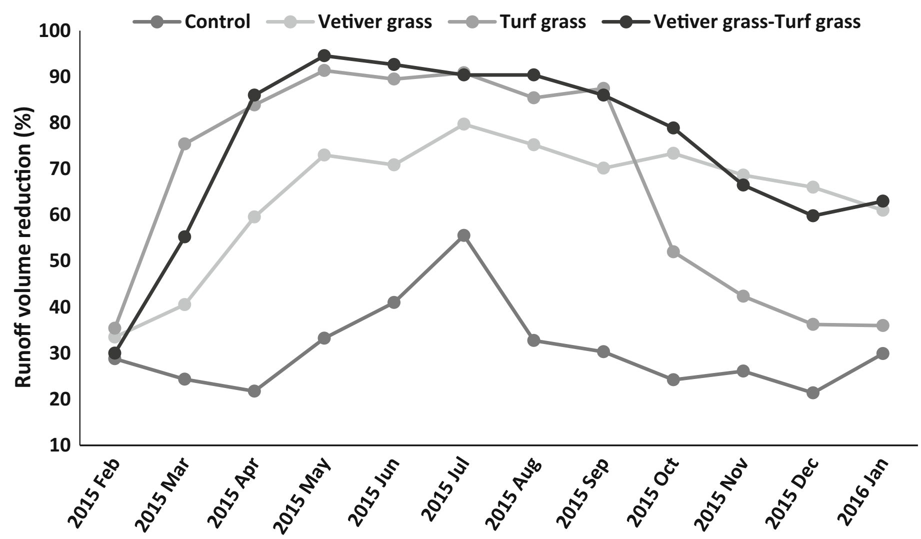

Fig. 5 Variations of mean runoff volume reduction in the four studied treatments during the experiment

the rainfall and consequently increasing the soil moisture as well as reducing the permeability. It also should be noticed that the control (bare) plot reduced some of the runoff volume during the experiment representing the soil ability for reduction in the runoff volume. This result is consistent with Delgado et al. (1995).

Sediment concentration

The results indicated that the maximum efficiency was observed in the first, sixth, seventh, eighth, ninth, tenth, eleventh and twelfth months for the treatment of vetiver grass. Also, the best efficiency in the second month was obtained for the treatment of turf grass. The treatment of vetiver grass–turf grass presented the best performance for sediment removal in the third, fourth and fifth months. The highest efficiency during the experiment period was related to the treatment of vetiver grass–turf grass in the fifth month (Fig. 6).

According to the results of determining the efficiency of the studied vegetative buffer strips in sediment removal, the treatment of turf grass has had an appropriate performance to reduce the sediment concentration from the second to the fourth months which it is due to faster growth of turf grass compared to vetiver grass. Since the third month onwards when vetiver grass was fully grown, higher sediment removal was observed for the treatment of vetiver grass–turf grass compared to the turf grass. It is due to high ability of vetiver grass for sediment retention (Golabi et al. 2005). Moreover, the treatment of vetiver grass presented its ability in sediment retention since the fifth month so that, the treatment of vetiver grass showed a much better performance than the two other treatments in the sediment retention from the sixth month onwards. The observed efficiency drop for the treatment of turf grass since the fifth month is probably because of lower plant quality and uniformity caused by some unforeseen external factors such as grazing (that had not damaged the vetiver grass) as well as temperature reduction since the eighth month onwards which may cause inappropriate conditions for the growth of turf grass. An efficiency drop in sediment retention was also observed for all the studied treatments in the last 5 months of the experiment that can be caused by sedimentation in the strips during the time.

Nitrate

According to Fig. 7, the maximum efficiency of nitrate removal in the first, sixth, eighth, ninth, tenth, eleventh and twelfth months was seen in the treatment of vetiver grass, while the highest efficiency in the second and fourth months was for the treatment of the turf grass. The treatment of vetiver grass–turf grass also presented the best performance of nitrate removal in the third, fifth and seventh months. Totally, the best efficiency was related to the treatment of vetiver grass–turf grass in the fifth month.

The results of nitrate concentration show almost the same trend as the sediment concentration, while mean value of the sediment removal efficiency for the studied vegetative buffer strips is a little higher than nitrate removal that is probably due to dissolving the nitrate in the water. Of course, the mentioned results represent the correlation of nitrate and sediment concentration probably due to adsorbing nutrients by the fine sediments (Barling 1994).

Phosphate

The results shown in Fig. 8 indicate the maximum efficiency of phosphate removal for the treatment of vetiver grass in the first, sixth, seventh, eighth, eleventh and twelfth months. Also, the treatment of vetiver grass–turf grass showed the best performance in the second, third, fourth, fifth, eighth months jointly with treatment of vetiver grass, and the ninth month. As can be seen, the highest efficiency during the experiment was related to the treatment of vetiver grass–turf grass in the third month.

The treatment of turf grass showed a weak performance in phosphate removal compared with the two other studied treatments, while it was not so for the sediment and nitrate removal. It is probably due to low phosphate absorption by turf grass. The treatment of vetiver grass–turf grass showed the highest efficiency until the fifth month of the experiment; however, as mentioned before, the quality of turf grass dropped due to some factors and consequently, the efficiency of the mentioned plant was decreased. Therefore, the treatment of vetiver grass having an ascending trend until the fifth month, surpassed the treatment of vetiver grass–turf grass and showed the best performance in phosphate removal until the seventh month. In the eighth month, a significant reduction occurred in the efficiency of all the studied treatments particularly in the treatment of vetiver grass. The reason is the increase in the precipitation and the accumulation of pollutants in the buffer strips.

According to the results, the studied vegetative buffer strips presented a considerable effect on reducing the runoff volume and existing pollutants in it and finally, water and soil conservation. This result is consistent with the results obtained by many researchers (Patty et al. 1997; Lee et al. 2003; Hay et al. 2006; Mankin et al. 2007; Duchemin and Hogue 2009; Borin et al. 2010; Wang et al. 2012). Interesting point during the experiment is that the treatment of vetiver grass–turf grass showed the highest efficiency in the runoff volume reduction, sediment removal, nitrate removal and phosphate removal, representing a considerable impact and performance of the combination of turf grass and vetiver grass in the runoff quality and quantity control. This result is also consistent with Lee et al. (2003)'s results. However, the vulnerability of turf grass at low temperatures and grazing reduced the efficiency of vetiver grass–turf grass strip; hence, considering the climatic conditions of the region, selecting a plant species with a density and uniformity like the turf grass and high resistance, is recommended to be used in vegetative buffer strips.

During the experiments, mean concentration of the pollutants increased, because of occurring sediment and nutrients accumulation. This result is consistent with the results obtained by Osborne and Kovacic (1993), Bhattarai et al. (2009) and Stutter et al. (2009). Therefore, the vegetative

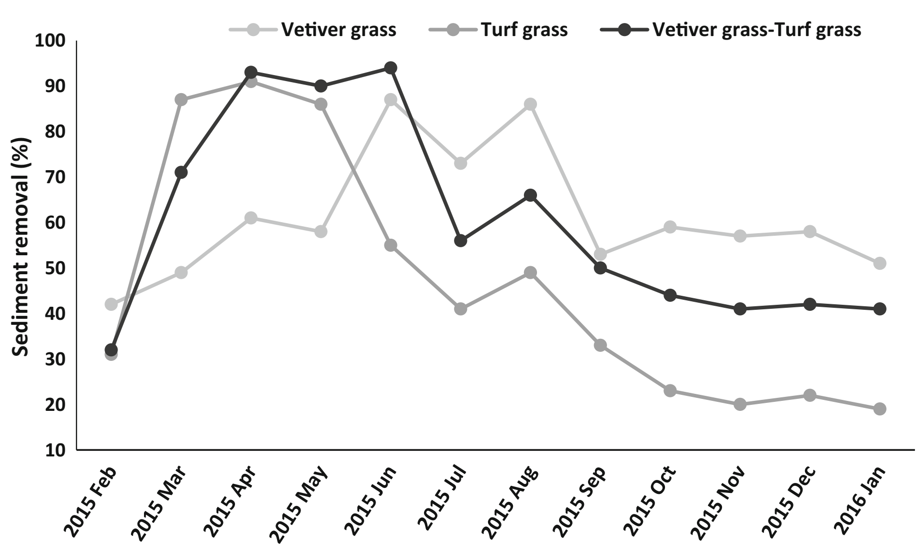

Fig. 6 Variations of sediment removal efficiency for the studied vegetative buffer strips during the experiment

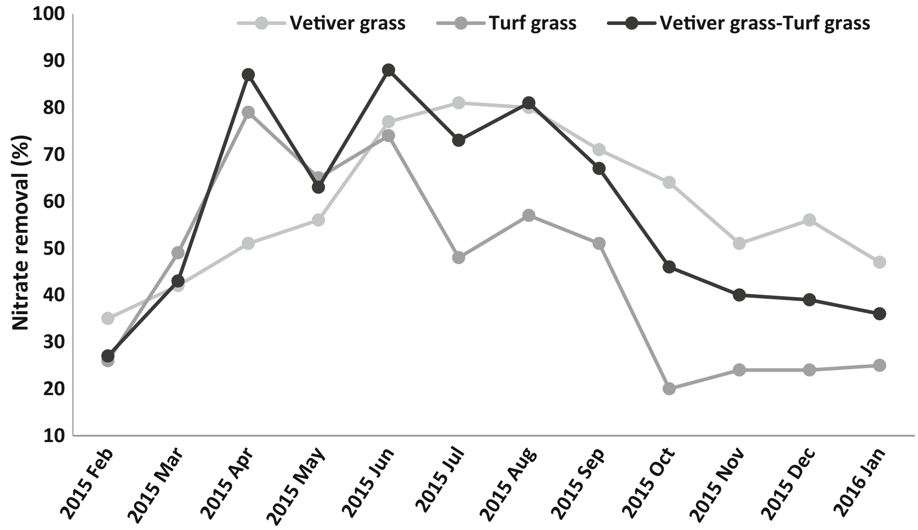

Fig. 7 Variations of nitrate removal efficiency for the studied vegetative buffer strips during the experiment

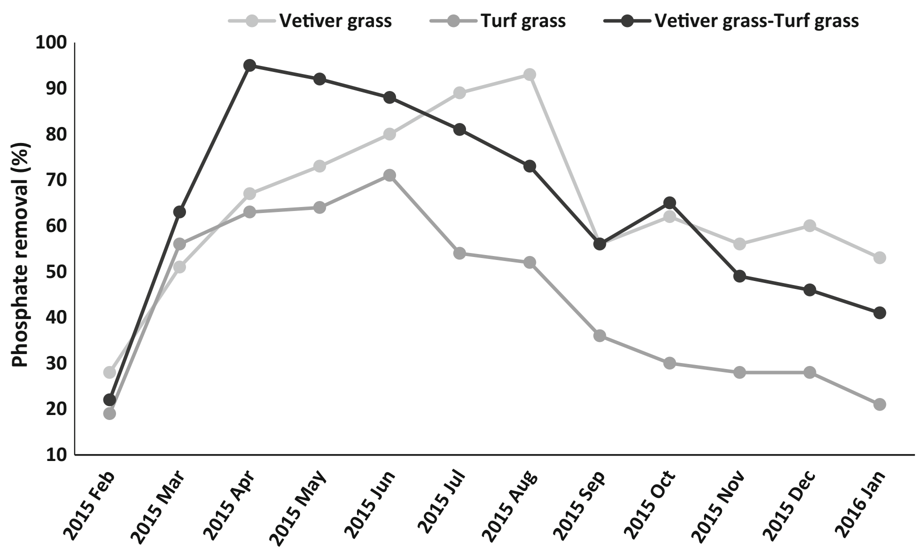

Fig. 8 Variations of phosphate removal efficiency for the studied vegetative buffer strips during the experiment

buffer strips can play an important role as the source of nutrients and sediment. Of course, reduction in the concentration of the pollutants in the last months is due to high precipitation and consequently leaching the contaminants from the plots surface.

As it was observed, the growth stage of the plant has a considerable role in sediment concentration control so that the vetiver grass showed a more appropriate performance in the pollutants removal as compared with the other studied vegetative buffer strips over the time, which is consistent with Borin et al. (2010)'s results. In addition, the plant species used in the buffer strips had a significant impact to runoff quality and quantity control. For instance, the treatment of vetiver grass–turf grass lost its highest efficiency among the studied plant species after a short time due to inappropriate conditions for sufficient growth and density of the turf grass especially in the cold seasons. This result also has been reported by Mankin et al. (2007).

Conclusion

It was concluded that the application of the vegetative buffer strips containing a combination of vetiver grass and a plant species with a density and uniformity like the turf grass resistant and compatible to the climatic conditions of the studied region can be a proper strategy to enhance the efficiency of the vegetative buffer strips for water and soil conservation as well as quality and quantity control of the runoff flowing over the cultivated lands in slopes being limited by water bodies.

The results of this study showed that the vegetative buffer strips can play role as a source of nutrients and sediment. In order to eliminate this problem, the periodic cutting of the plants is recommended as an effective strategy. In addition, doing researches on the impact of rainfall intensity, rainfall amount and soil moisture on the efficiency of the vegetative buffer strips in water and soil conservation can be helpful for amplifying the impact of these strips in the water and soil conservation in different watersheds.

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