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The effect of physical and chemical treatments on runoff, infiltration and soil loss

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ABSTRACT- In recent years, intensive drought has caused a severe yield reduction in rain-fed trees. Increasing runoff of low amount rainfall can be used to provide partial water requirement of rain-fed trees. To achieve this objective, some strategies including gravel removal (G), rill construction across to slope (R) and applying of baking soda (S) and their effects on runoff, rainfall infiltration and soil loss were simulated by a laboratory rainfall simulator under 33 mm h^{-1} intensity in 60 minutes. The results showed that the combination of R^+, G^- and S^+ significantly increase the soil loss, runoff, and runoff coefficient 14.43, 2.74 and 1.59 and decrease rainfall threshold and infiltration 2.1 and 1.57 times compared to the control, respectively. Separately, S^+, R^+ and G^- were the most effective in the runoff enhancement (31.2, 29.3 and 22%) and in infiltration reduction (8.4, 7 and 5%), respectively. S^+ had the most effect on soil loss due to dispersion of soil surface. Furthermore, the effect of R^+ was more visible than G^- in increasing the soil loss. Applying sodium bicarbonate (S) increased the sodium in runoff and sediment, but there were no salinity (EC= 0.51-0.60 dS m^{-1}) and sodicity (SAR= 0.34-0.73) hazard in runoff. In saturated extract of sediment, the salinity (EC= 1.75-2.23 dS m^{-1}) and sodium (SAR= 1.96-3.45) hazard were relatively high and low, respectively. Although, chemical treatments (S) did not show the sodicity hazard very much, the use of S must be considered carefully.

INTRODUCTION

Most parts of Iran are located in the arid and semiarid regions. These regions have always been faced with shortage of water. These conditions resulted in cultivated rain-fed trees (almond, fig, olive, and grape) on a wide range of hill slopes exposed to water stress. In water-scared areas, water, not land, is the primary limiting factor to improving agricultural production. Rainwater harvesting (RWH) is one of the promising ways of supplementing the surface and underground scarce water resources in areas where existing water supply system is inadequate to meet demand (Aladenola and Adeboye, 2010). Water harvesting can substantially increase rainwater productivity in the drier marginal environments (Oweis and Hachum, 2006). RWH provides a source of free natural soft water which can serve non-portable indoor usages with only storage and treatment costs, augment limited quantities of groundwater and reduce stormwater runoff. It reduces erosion and non-point pollution in urban environments. In addition to its potential to generate considerable quantities of water, RWH results in the collection of decentralised water which makes it less expensive when compared with well drilling and water supply from the public taps (Krishna, 2005). Ali et al. (2010) assessed the micro-catchments RWH potential of a Mediterranean arid environment by using runoff micro-catchment and soil water balance approaches and showed a maximum water harvesting potential of the microcatchments RWH. Therefore, in addition to existing gravitational and non-gravitational methods such as water extraction from rivers, earth and concrete dams, wells, springs and aqueducts, the rainwater harvesting systems must be considered especially in arid and semi-arid regions (Sepaskhah et al., 1992; Hosseini-Abrishami, 1994; Serajzadeh, 2007). Some investigators studied the traditional and recent water harvesting methods (Farshad and Zinck, 1998; Noroozi and Ghoddousi, 2001; Tahmasebi and Rajabi-Sani, 2006; Arzani, 2010; Gammoh, 2013). For example, the new water harvesting micro-catchment technique (wide furrow with back-placed transplanting area) implemented using newly designed inexpensive furrow-opener proved to be a potential furrow opening technique for rehabilitating large areas of the east

Mediterranean arid environment compared to a popular technique (the deep furrow) by Gammoh (2013). The collection of runoff as a solution for the water shortage problem in arid and semi-arid regions in Iran were studied by Tahmasebi and Rajabi-Sani (2006). They indicated that if a portion of runoff is stored in a pool and another portion in the root zone, rain-fed tree cultivation is possible in arid and semi-arid regions of Iran with similar rainfall, climatic and soil conditions as the study area. RWH which applies water directly into the field ranges from in-situ techniques such as contour ridging, deep ploughing, terracing, which prevent runoff and promote infiltration where rain falls directly on the crop area (Mzirai and Tumbo, 2010). Our ancestors constructed terraces across to the slope to collect the runoff around the rain-fed trees to provide their water requirement in arid and semi-arid areas of Iran. However, amounts and events of rainfall during the growing season generally are not enough in these regions. Besides, due to the coarseness of soil texture in hill slopes and existence of stone cover, large amounts of rainfall rapidly infiltrate into the soil and not transfer around the trees. Therefore, it is vital to investigate the relationship between rainfall, soil surface condition, infiltration, runoff and soil loss to increase the runoff from the rainfall with low amounts and transfer it to tree sites in micro-catchment RWH. The presence of different slopes and surface conditions on the soil surface, such as rock fragments and anticident soil moisture conditions can have a sizeable influence on hydrological and erosive behavior (Romkens et al., 2001; Javadi et al., 2005; Ruiz-Sinoga et al., 2010; Defersha et al., 2011; Smets et al., 2011). Guo et al. (2010) showed that surface stone cover had significant impacts on runoff, soil loss, and solute transport in terms of stone cover percentage and stone size. Martínez-Murillo et al. (2013) observed that rainfall intensity, runoff coefficient, and slope angle had a positive influence on sediment concentration and sediment detachment and in the case of rock fragment cover, its influence was variable according to the soil cover percentage. The increase in infiltration rate and the decrease in soil loss with increase rock fragment were reported by Martinez-Zavala and Jordan (2008), Martinez-Zavala et al. (2010) and Wang et al. (2012). Increased runoff via gravel removal (G) has been established by previous researches (Jung, 1960; Epstein et al., 1966; Agassi and Levy, 1991; Chow et al., 1992; Nyssen et al., 2001). In addition, it is known that rill construction across to slope (R) increases runoff. Furthermore, the application of some chemical-materials is able to change the soil characteristics (S) to increase or decrease runoff. The main objectives of this study were to present the strategies for increasing the runoff from the rainfall with low amounts for supplying the water requirement of rain-fed trees and study the effects of gravel removal (G), rill construction across to slope (R) and application of baking soda (S) on runoff, rainfall infiltration and soil loss of a medium texture soil with 5% slope under a laboratory rainfall simulator.

MATERIALS AND METHODS

Rainfall Simulator

To simulate the rainfall, a rainfall simulator (model FEL 3, ELE Company) was used (Anonymous, 1998). The maximum entrance flow rate, rainfall height and area of sprinkled-water were 1.5 L s^{-1}, 2.65 m and 1.65×1.65 m^2, respectively. The most important factor for choosing a simulated rainfall instead of natural rainfall is coefficient of uniformity of simulated rainfall. Therefore, after many experiments, the rainfall with lower intensity (33 mm h^{-1}) and acceptable uniformity (70 percent) was used.

Soil Characteristics

Kooye-Asatid soil series with loamy texture and loamy-skeletal over fragmental, carbonatic, mesic, fluventic xerorthents classification located in Shiraz University College of Agriculture (Bajgah) in 16 km north of Shiraz city and from the plug layer (0-20 cm) was used. It is similar to the soil texture of hill slopes with rain-fed plantations of fig trees in Estahban area, Fars province, Iran. The mean values of initial volumetric soil moisture content for different treatments varied between 9.23-12.86 %. Some physical characteristics of soil are shown in Table 1.

Treatments Preparation

Eight steel boxes (1.4m ×1.4m × 0.09 m) were used for the study. The funnel head was attached to each box for collecting the runoff and sediment into catch containers (Fig. 1). The experiment was conducted at slope of 5.0%. A mesh plate, including 2 mm radius holes was located at 10 mm from the bottom of each box and covered with paper sheet. The reason for choosing this slope was a simulation of the natural hill slope condition of rain-fed tree cultivation areas. Four physical treatments including 2 treatments with gravel removal by sieving soil with 8 mm sieve (without gravel), and other 2 treatments without soil sieving (with gravel) were chosen.

Table 1. Some physical and chemical characteristics of Kooye-Asatid soil series.

Clay (%)	Silt (%)	Sand (%)	Texture	EC_e (S m^{-1})	pH	Stone cover (%)	ρb (g cm^{-3})	Organic matter (%)
13	46	41	Loam	0.042	7.8	7.05	1.28	1.1

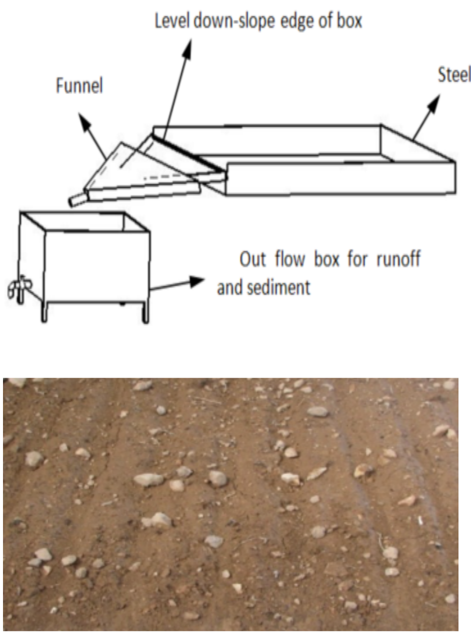

Fig. 1. Schematic diagram of the soil tray, runoff and soil erosion collection accessories, sampling box and soil surface conditions in treatments with gravel.

In addition, the rill treatments with 50-70 mm width and 30-40 mm depth were made in half of the treatments with and without gravel. To simulate the resemblance rill size, the rill size was selected similar to those made by disk and harrow in rain-fed tree cultivation. To apply chemical treatments, 600 kg ha^{-1} baking soda ($NaHCO_3$) was mixed with 20 mm soil surface layer and used to reduce infiltration rate considerably. Therefore, the experimental treatments were as follow: with gravel, rill and soda treatment ($G^+R^+S^+$); with gravel, rill and without soda treatment ($G^+R^+S^-$); with gravel, without rill and with soda treatment ($G^+R^-S^+$); with gravel, without rill and soda treatment, the control ($G^+R^-S^-$); without gravel, rill and soda treatment ($G^-R^-S^-$); without gravel, with rill and without soda treatment ($G^-R^+S^-$); without gravel, rill and with soda treatment ($G^-R^-S^+$) and without gravel, with rill and soda treatment ($G^-R^+S^+$). In treatments with rill, soda was mixed with soil surface before rills construction. The stone cover percentage of the soil surface varied from 5.68 to 8.31 % in treatments with gravel.

Experimental Measurements

The experimental design was completely factorial randomized with factorial arrangement of three factors as 2 × 2 × 2 = 8. These factors were soil gravel levels, G (with and without), rill, R (with and without) and chemical material levels, S (with and without baking soda). The measured parameters were runoff, infiltration and soil loss which were the variables to be analyzed. Each treatment was conducted in three replications with 33 mm h^{-1} simulated rainfall intensity whose means were compared statistically by Duncan's multiple range test by MSTAT-C software. This intensity was used to simulate the real rainfall intensity of spring and summer (growth season of rain-fed fig trees) in arid and semi-arid areas of Iran. The experiment duration for each treatment was 60 minutes because in all treatments, the runoff starting time was less than 22 minutes and the infiltration rate was stabilized after 45 minutes in pre-experiments for the worst infiltration condition (applying baking soda).

After different elapsed times from the start of the experiments, the runoff appeared from the end of soil trays (time to runoff starting). Then, runoff was immediately measured in 150 s intervals. Infiltration in different time intervals was determined by the difference between rainfall and runoff. Accumulated infiltration was also calculated from summation of these amounts.

To determine the final infiltration rate (FIR), the equation of accumulated infiltration as a function of elapsed time was firstly determined. Then, infiltration rate was obtained by derivation of the accumulated infiltration equation. Mathematically, when the second derivative of the equation of accumulated infiltration is 5 % of its first derivative, infiltration rate is assumed to reach the FIR.

For determining the soil loss, runoff was collected in a container during the experimental period and then to evaporate the water, it was left several weeks under sunshine and the remained dry sediment was weighted.

Chemical Analysis of Sediment Saturation Extract and Runoff

To determine the quality of transferred runoff and sediment, the electrical conductivity and chemical characteristics in the sediment saturation extract, runoff, soil saturation extract (before applying baking soda) and applied water were analyzed in four treatments with applying baking soda. In these treatments, soil saturation extract and applied water were analyzed before the experiments and sediment saturation extract and runoff after the experiments. Furthermore, to analyze calcium and magnesium, carbonate and bicarbonate and electrical conductivity, titration with standard EDTA solution, titration with standard sulfuric acid and conductivity meter were used, respectively.

RESULTS AND DISCUSSION

Interaction between Factors

The analysis of interaction effects between gravel removal (factor A), rill construction (factor B) and applying chemical material (factor C) showed that all factors had a significant effect on runoff generation, soil loss, accumulated infiltration and runoff coefficient. Furthermore, interaction effects between A and B, A and C, B and C, and A, B, C were significant (Table 2).

Table 2. Analysis of interaction effects between gravel removal (factor A), rill construction (factor B) and applying chemical material (factor C) on runoff generation, soil loss, runoff coefficient and accumulated infiltration.

Source	DF	Run off (mm)		Soil loss (kg ha^{-1})		Runoff coefficient		Accumulated infiltration (mm)	
		Fvalue	Pvalue	Fvalue	Pvalue	Fvalue	Pvalue	Fvalue	Pvalue
Factor A	1	3.3E+3	< .05	2.0E+5	< .05	5.4E+2	< .05	2.7E+2	< .05
Factor B	1	1.9E+3	< .05	9.4E+2	< .05	1.7E+3	< .05	1.7E+2	< .05
Factor C	1	2.7E+3	< .05	1.4E+5	< .05	1.5E+3	< .05	3.3E+2	< .05
AB	1	3.4E+2	< .05	6.7E+2	< .05	6.5E+2	< .05	3.5E+1	< .05
AC	1	3.4E+2	< .05	1.2E+5	< .05	7.1E+1	< .05	4.7E+1	< .05
BC	1	5.2E+2	< .05	8.6E+2	< .05	2.2E+2	< .05	4.8E+1	< .05
ABC	1	2.0E+2	< .05	6.5E+2	< .05	1.0E+2	< .05	3.2E+1	< .05

Runoff Starting Time

Based on Table 3, except $G^-R^-S^-$, other treatments were significantly different from $G^+R^-S^-$ (control), and decreased runoff starting time. Furthermore, the results showed that removing the gravel, constructing the rill across the slope and adding the baking soda in soil surface ($G^-R^+S^+$) had the most significant effect on runoff starting time and decreased it 80% compared to the control. However, more effect was related to R^+ in comparison with G^- and S^+. As expected, the runoff starting time was the fastest at the soil plots without gravel (G^-) compared to soil plots with gravel. In agreement with our results, Martinez-Zavala et al. (2010) demonstrated that increasing the average rock fragment cover from 44 to 68% increased the time to runoff 70% in sandy loam soils.

Runoff Generation

Significant differences between treatments and the control showed that all treatments increased the runoff in comparison with the control. Based on Table 3, increased runoff for $G^-R^-S^-$, $G^-R^+S^-$, $G^+R^+S^-$, $G^-R^-S^+$, $G^-R^+S^+$, $G^+R^-S^+$ and $G^+R^+S^+$ were 17.4, 61.1, 25.2, 62.8, 174.0, 36.0 and 67.7 %, respectively compared to $G^+R^-S^-$ (control). In general, it is concluded that gravel removal (>8 mm) increased the runoff in treatments that were similar in all factors except gravel content (> 8 mm). The incorporated and the rest of gravels in soil surface occupied 5.7-8.3 % of the soil surface. All treatments increased the runoff and $G^-R^+S^+$ indicated most runoff (31.33 L) while runoff in the control was 11.43 L. Poesen and Ingelmo-Sanches (1992) reported that the existence of gravel cover lead to increasing or decreasing erosion and runoff depending on the size and content of gravel in the soil surface. In agreement with our results, some researchers showed that removing gravel in soil surface increased the runoff. Epstein et al. (1966) concluded that the removal of gravel larger than 38 mm from soil surface increased runoff and soil loss, and decreased infiltration and soil moisture. Jang (1960) showed that the removal of stone cover from soil surface increased the runoff. Furthermore, Guo et al. (2010), Martinez-Zavala et al. (2010) and Wang et al. (2012) indicated that the runoff rate decreased as stone cover percentages increased. However, the general belief is that the existence of stone cover influences the runoff based on the size of gravels and the kind of its standing. In general, the results showed that gravel removal increases the runoff. To study the independent effects of different factors (G, R and S), the treatments which were similar in one factor but different in others, were compared. Therefore, to determine the effect of S, the $G^+R^-S^-$, $G^-R^-S^-$ and $G^+R^+S^-$ were used as control for $G^+R^-S^+$, $G^-R^-S^+$ and $G^+R^+S^+$, respectively. For R factor, the $G^+R^-S^-$, $G^-R^-S^-$ and $G^+R^-S^+$ were used as control for $G^+R^+S^-$, $G^-R^+S^-$ and $G^+R^+S^+$, respectively, and finally for G, the $G^+R^-S^-$, $G^+R^-S^+$ and $G^+R^+S^-$ were used as control for $G^-R^-S^-$, $G^-R^-S^+$ and $G^-R^+S^-$, respectively. This analysis showed that the S^+ factor increased the runoff 36.0, 38.8 and 18.5%. Also, R^+ factor increased it 25.2, 37.3 and 25.3% and finally, the G^- increased the runoff 28.7, 19.7 and 17.7%, respectively. Therefore, on average, S^+ factor was more effective than R^+ and R^+ was more effective than G^-. Therefore, the rank of various factors in runoff increasing was as follows: S^+ (31.2%)>R^+ (29.3%) >G^- (22 %). In general, the results showed that the applied strategies to increase the runoff in our study were effective and useful to supply the demand of rain-fed trees in arid and semi-arid areas.

Runoff Coefficient and Rainfall Threshold

The relationship between the rainfall and measured runoff at different times after the experiment initiation was linear and as fallow:

$$R_u = a(R_a - b) \tag{1}$$

where R_u and R_a are the runoff and rainfall in mm, respectively, b is the rainfall threshold in mm and a is the runoff coefficient. The runoff coefficient (a) is the ratio of accumulated runoff to accumulated rainfall in mm and rainfall threshold (b) is the amount of rainfall at the runoff starting time. Higher values of the runoff coefficient indicate the more runoff. For determining the slope of Equation 1 (a), the linear relationship fitted to rainfall and runoff data. Runoff coefficient, rainfall threshold and fitted equations for different treatments are presented in Tables 3 and 4, respectively.

Table 3. Mean values of accumulated runoff, runoff coefficient, rainfall threshold, runoff ponding time, final infiltration rate, soil loss and cumulative infiltration in different treatments

Treatment	Accumulated runoff (L)	Runoff coefficient	Rainfall threshold (mm)	Runoff ponding time (min)	Final infiltration rate (mm h^{-1})	Soil loss (kg ha^{-1})	Cumulative Infiltration (mm)
$G^-R^-S^-$	13.41 f *	0.438 e	17.2 b	20.9 a	1.47 b *	127.9 e	25.7 b
$G^-R^+S^-$	18.41 c	0.514 b	14.6 c	15.8 c	1.10 e	179.4 d	23.4 cd
$G^+R^-S^-$	11.43 g	0.413 f	18.7 a	21.6 a	1.64 a	112.4 f	26.8 a
$G^+R^+S^-$	14.31 e	0.460 d	16.8 b	19.7 b	1.39 cd	177.6 d	24.9 b
$G^-R^-S^+$	18.61 c	0.502 c	14.8 c	10.0 d	1.43 bc	415.0 b	23.9 c
$G^-R^+S^+$	31.33 a	0.658 a	8.9 e	4.5 f	0.82 f	1622.1 a	17.1 e
$G^+R^-S^+$	15.55 d	0.419 f	14.2 c	16.4 c	1.41 c	210.9 c	25.1 b
$G^+R^+S^+$	19.49 b	0.461 d	11.7 d	8.3 e	1.35 d	1619.6 a	22.8 d

* The values showed with different alphabet represent the difference is significant at 5% probability level.

Results showed that with keeping the R and S constant, Gincreased the runoff coefficient and decreased the rainfall threshold. Furthermore, this trend was observed for R^+ when the G and S were kept constant. However; in presence of gravel (G^+), S^+ had no significant effect on the runoff coefficient and rainfall threshold while in the absence of gravel (G^-), the runoff coefficient significantly increased and the rainfall threshold decreased. According to Table 3, $G^-R^+S^+$ was the most effective in decreasing rainfall threshold whose value for all treatments was less than the control ($G^+R^-S^-$) and these differences were significant at 5 % probability level (p=0.05). Fig. 2 shows the relationship between the runoff and rainfall in $G^+R^-S^+$ and $G^+R^+S^+$ (as an example) and Fig. 3 represents the fitted equation to different treatments. Table 3 shows that the differences between $G^-R^+S^+$ and other treatments were significant (p=0.05).

Table 4. Fitted equations between runoff and rainfall for different treatments

Treatment	Fitted linear equations	R^2
$G^-R^-S^-$	R_u=0.44(R_a-17.2)	0.998
$G^-R^+S^-$	R_u=0.51(R_a-14.6)	0.998
$G^+R^-S^-$	R_u=0.41(R_a-18.7)	0.996
$G^+R^+S^-$	R_u=0.46(R_a-16.8)	0.994
$G^-R^-S^+$	R_u=0.51(R_a-14.8)	0.997
$G^-R^+S^+$	R_u=0.66(R_a- 8.9)	0.999
$G^+R^-S^+$	R_u=0.42(R_a-14.2)	0.997
$G^+R^+S^+$	R_u=0.46(R_a-11.7)	0.997

Infiltration

Accumulated Infiltration and Final Infiltration Rate (FIR). As an example, in $G^-R^-S^-$ and $G^-R^+S^-$, the cumulative infiltration as a function of elapsed time is presented in Fig. 4. Further, Table 3 shows cumulative infiltration at 60 min for different treatments. Based on the results, the differences between all treatments and the control ($G^+R^-S^-$) were statistically significant and all of them decreased the infiltration compared to the control ($G^+R^-S^-$). Factor G^+ increased the accumulated infiltration where the two other factors (R and S) were kept constant. However, the maximum increase in accumulated infiltration (33%) due to gravel cover (G^+) was observed in the soil plot with S^+ and R^+. In contrast to our results, some studies obtained opposite results (Wilcox et al., 1988; Abrahams and Parsons, 1991; Valentin and Casenave, 1992).

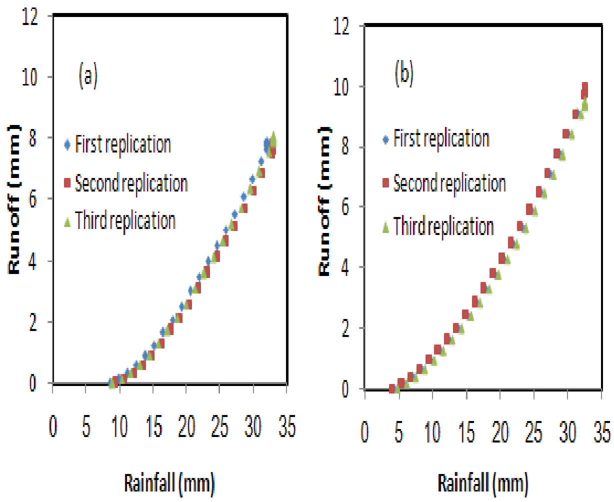

Fig. 2. The relation between runoff and rainfall in $G^+R^-S^+$ (a), and $G^+R^+S^+$ (b) treatments

Wilcox et al. (1988) showed that although some of the stone covers had safeguard effects, particularly when their diameters were greater than 25 mm, in general, stone cover had inverse relation with infiltration. This inverse relationship was more evident for gravels with a small diameter. Furthermore, they concluded that the increase in clay content for clay loam and silty clay loam textures enhance the infiltrability, possibly due to soil aggregation increase. But, in our study, a loam texture with a lower amount of clay was used. The lowest amounts of cumulative infiltration were obtained for $G^-R^+S^+$ (36.2%) compared with control ($G^+R^-S^-$).

This reduction occurred wherever the physical and chemical treatments were used together. These results confirmed the effective role of physical and chemical treatments in the reduction of cumulative infiltration. To determine the independent effects of physical and chemical treatments on cumulative infiltration, analyses like runoff were carried out. In average, the rank of decrease in cumulative infiltration by various factors was as follows: S^+ (8.4%) >R^+ (7%) >G^- (5%).

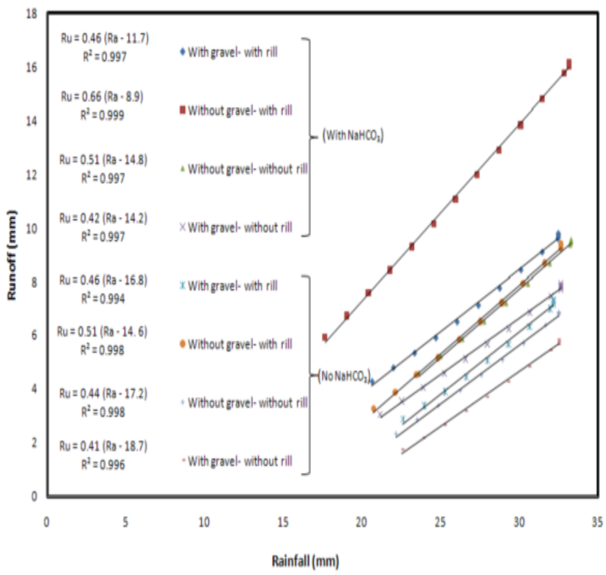

Fig. 3. Fitted equations between runoff and rainfall in different treatments

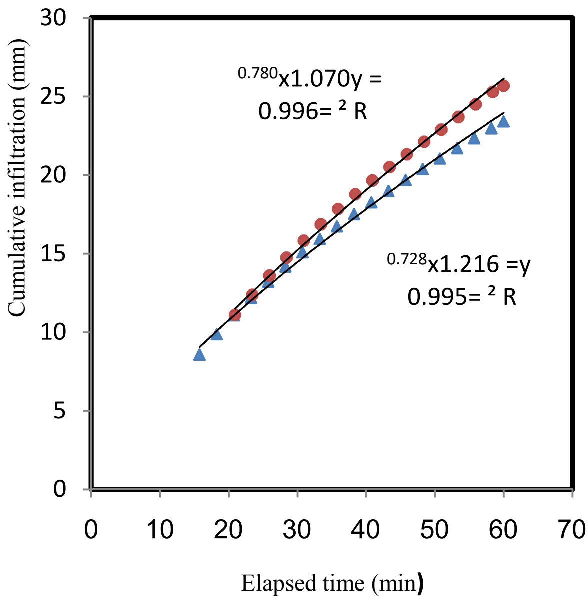

Fig. 4. Mean cumulative infiltration (I) as a function of elapsed time (t) in $G^-R^-S^-$ (●), and $G^-R^+S^-$ (▲) treatments

The positive effects of rock fragment cover on surface runoff generation, on the one hand, and the negative effect on subsurface runoff initiation, on the other hand, show that soils with greater rock fragment cover are more readily infiltrated. This is confirmed by the properties related to soil hydrology: the steady-state (final) infiltration rate, surface runoff rate and subsurface runoff rate (Wang et al., 2012). Based on Table 3, all treatments reduced final infiltration rate (FIR) and the $G^-R^+S^+$ was the most effective treatment in decreasing the FIR. This treatment reduced FIR 50.8 % compared with the control ($G^+R^-S^-$). G^+ factor enhanced the FIR where the other two factors (S and R) were kept constant. This finding demonstrated the positive effect of gravel on infiltration and FIR. Our results were in agreement with the results of Mandal et al. (2005), Martinez-Zavala and Jordan (2008), and Martinez-Zavala et al. (2010) that confirmed the role of rock fragment in the enhancement of FIR.

Soil Loss

The presence of gravel affects the amount of sediment detachment because it protects the soil surface against raindrop impact. According to Table 3, the chemical and physical treatments increased soil loss and $G^-R^+S^+$ and $G^+R^+S^+$ showed the maximum values of soil loss increasing with 1343 and 1341%, respectively. Furthermore, results showed that the difference between $G^-R^+S^-$ and $G^+R^+S^-$ treatments and $G^-R^+S^+$ and $G^+R^+S^+$ was not statistically significant (p=0.05). Two by two comparisons between $G^-R^-S^-$ and $G^+R^-S^-$, $G^-R^+S^-$ and $G^+R^+S^-$, $G^-R^-S^+$ and $G^+R^-S^+$ and $G^-R^+S^+$ and $G^+R^+S^+$ showed that the soil plots without gravel produced higher soil loss than rough surface with gravel. However, in treatments with R^+ factor, the effect of G^- on increasing soil loss was not significant. This was in agreement with the results of some previous studies. Wang et al. (2012) found that surface rock fragments reduced soil loss significantly and the relationship between soil loss ratio and rock fragment cover could be expressed by an exponential function, with a high degree of reliability regardless of rainfall intensities. Martinez-Zavala and Jordan (2008) showed that soil loss values were smaller in soils with greater rock fragment cover while rock fragment cover ranged from 3% to 85%. Furthermore, the decrease in soil loss as stone cover percentages increased from zero (no stone cover) to 20.8% was reported by Guo et al. (2010). Moreover, they showed that the smaller stone sizes caused lower soil loss than bigger ones at the same stone cover percentage of 5.1%. The effect of subsurface rock fragments in topsoils (i.e. not visible at the soil surface) was investigated by Smets et al. (2011). They showed that the impacts and complexity of subsurface rock fragments on the production of soil loss resulted in the decrease of soil loss with increasing the depth of subsurface rock fragment while the size of rock fragment had no significant effect on soil loss. In general, our results demonstrated that the R^+, S^+ and G^- factors led to increasing the soil loss, but this increase in the arid and semi-arid areas with rain-fed tree cultivation is not worrying because the catchment is divided into thousands of micro catchments and soil erosion occurs in these micro catchments. Therefore, the movement of eroded soil only occurs several meters and then mixes with litter and is re-attached to the soil in the site of trees. So, the soil erosion does not happen in a large scale.

Quality of Runoff in Chemical Treatments

The mixed baking soda is washed out and transported by runoff. Chemical analysis of soil saturation extract and applied water in the experiments are shown in Table 5 and the results for runoff and sediment saturation extracts analysis for chemical treatments are also shown in Table 6. Results indicated that applying sodium bicarbonate in soil increased the sodium in runoff and sediment and also decreased divalent cations such as calcium and magnesium. According to Table 6, SAR varied between 0.34-0.73 and salinity 0.051-0.060 S m^{-1} in runoff; therefore, runoff had no salinity and sodicity hazards. Furthermore, applying 600 kg ha^{-1} sodium bicarbonate did not show destructive impacts on runoff quality. The SAR and EC_e of saturated extract of sediment varied between 1.96-3.45 and 0.175-0.223 S m^{-1}, respectively. Therefore, salinity and sodium hazards were relatively high and low, respectively (Richards, 1954). In water with a relatively high value of bicarbonate, the tendency of calcium and magnesium to deposition is high. This chemical reaction subsequently increased SAR of soil solution and exchangeable sodium percent (ESP). Eaton (1950) offered that with the assumption of depositing all calcium and magnesium in the form of carbonate, residual sodium carbonate (RSC) is calculated as below:

$$RSC = (CO_3^{-2} + HCO_3^{-}) - (Ca^{+2} + Mg^{+2}) \qquad (2)$$

In this equation, the units are meq L^{-1}. RSC is used as a criterion to evaluate the carbonated water. With this basic, the water with RSC more than 2.5 meq L^{-1} is not suitable for irrigation. Water containing 1.25 to 2.5 meq L^{-1} is marginal and water with RSC less than 1.25 meq L^{-1} is probably safe (Richards, 1954). According to Table 6, the RSC in runoff was -0.4 to -1.5 meq L^{-1} in different chemical treatments and showed that the runoff was suitable for irrigation. However, the values of RSC for the saturated extract of sediment were -6.5 to -10 meq L^{-1} and showed that the use of bicarbonate for increasing the runoff is safe.

CONCLUSIONS

Combining physical and chemical treatments showed the most effectiveness in increasing runoff, soil loss and decreasing infiltration. In general, S^+, R^+ and G^- were the most effective factors in increasing runoff and decreasing infiltration, respectively.

Although the maximum soil loss occurred in conjugation of chemical and physical treatments, it was more affected by the chemical treatment (S^+) due to the change in the characteristics of soil surface. This treatment showed the most effect on the intensity of rill erosion and increase of soil loss. Furthermore, the effect of R^+ was more visible than G^- in increasing the soil loss.

The use of R is useful for the better transfer of runoff to trees under rain-fed conditions in hill slopes. Results of G may be different in various conditions for stone cover and type of stone standing. Therefore, to determine the effect of G, the size of stone cover and the type of stone standing must be investigated. In addition, in the absence of R^+ and S^+, the G^- did not increase the runoff considerably.

Table 5. Chemical analysis of soil saturation extract and water used (parenthesis) in this experiment

EC (S m^{-1})	Magnesium (mg kg^{-1})	Calcium (mg kg^{-1})	Sodium (mg kg^{-1})	SAR	Carbonate (mg kg^{-1})	Bicarbonate (mg kg^{-1})	RSC (meq L^{-1})
0.042	72	140	5.98	0.11	0	119	-9
(0.045)	(43.2)	(76)	(14.3)	(0.32)	(0)	(18.3)	(-7.10)

Table 6. Chemical analysis of saturation extract for sediment (parenthesis) and runoff in chemical treatments

Treat ment	EC (S m^{-1})	Magnesium (mg kg^{-1})	Calcium (mg kg^{-1})	Sodium (mg kg^{-1})	SAR	Carbonate (mg kg^{-1})	Bicarbonate (mg kg^{-1})	RSC (meq L^{-1})
$G^-R^-S^+$	0.053(-)	60 (132.0)	50 (80)	25.8 (212.3)	0.58 (3.37)	0 (0)	366.1(305.1)	-1.50 (-10.0)
$G^-R^+S^+$	0.060 (0.175)	42 (90)	38 (70)	27.4 (105.8)	0.73 (1.96)	0 (0)	305.1(244.0)	-0.40 (-6.50)
$G^+R^-S^+$	0.054 (0.223)	50.4 (123)	76 (75)	15.4 (198.3)	0.34 (3.26)	0 (0)	402.1(305.1)	-1.40 (-9.0)
$G^+R^+S^+$	0.051(-)	45.6 (120)	44 (70)	18.6 (205.9)	0.43 (3.45)	0 (0)	292.1(289.1)	-1.20 (-8.75)

Furthermore, the results showed that despite the positive effect of sodium bicarbonate (S^+) on increasing the soil loss, the negative effects of S^+ factor on chemical characteristics of runoff and soil were not noticeable. However, S treatment must be used carefully.

Of course, in chemical treatments, the sediment with sodium content is mixed with original soil under trees and, therefore, the sodium hazard is decreased. Although chemical treatments did not increase the sodocity hazard very much, the use of chemical treatments for sensitive plants must be considered carefully. The sodium bicarbonate can be used as a runoff enhancement agent by regarding the suitable management of water and soil salinity.

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تحقیقات کشاورزی ایران (۱۳۹۵) ۳۵(۲) ۹-۱۸

مطالعه اثر تیمار های فیزیکی و شیمیایی خاک بر رواناب، نفوذ و هدر رفت خاک

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چکیده- در سال های اخیر خشکسالی های شدید، سبب کاهش چشمگیر محصول انجیر دیم شده است. افزایش رواناب حاصل از بارندگی های اندک می تواند برای تامین بخشی از نیاز آبی درختان انجیر دیم استفاده شود. برای رسیدن به این هدف استراتژی های مختلفی شامل عملیات فیزیکی حذف سنگریزه از خاک (G) و ایجاد شیار (R) و عملیات شیمیایی افزودن ماده شیمیایی بی کربنات سدیم (S) و تاثیر آن ها بر رواناب، نفوذ و هدر رفت خاک توسط دستگاه شبیه ساز باران در آزمایشگاه و تحت شدت ۳۳ میلی متر بر ساعت و به مدت ۶۰ دقیقه شبیه سازی گردید. نتایج نشان داد که نسبت به تیمار شاهد ترکیب سه استراتژی به طور معنا داری هدر رفت، رواناب و ضریب رواناب را به ترتیب ۱۴/۴۳، ۲/۷۴ و ۱/۵۹ برابر افزایش و حد آستانه بارش و نفوذ را ۲/۱ و ۱/۵۷ برابر کاهش می دهد. موثرترین استراتژی ها بر افزایش رواناب به ترتیب S (۳۱/۲٪)، R (۲۹/۳٪) و G (۲۲٪) و بر کاهش نفوذ S (۸/۴٪)، R (۷٪) و G (۵٪) بودند. استراتژی افزایش ماده شیمیایی به دلیل ایجاد پراکنش ذرات سطحی خاک بیشترین تاثیر بر هدر رفت خاک را نشان داد. همچنین تاثیر شیار بر هدر رفت خاک بیشتر از حذف سنگریز بود. افزایش ماده شیمیایی باعث افزایش سدیم در رواناب و رسوب گردید اما این افزایش باعث خطر شوری ($EC= 0.051\text{-}0.060\ S\ m^{-1}$) و سدیمی شدن ($SAR= 0.34\text{-}0.73$) در رواناب نگردید. همچنین در عصاره اشباع رسوب خطر شوری ($EC= 0.175\text{-}0.223\ S\ m^{-1}$) و سدیمی شدن ($SAR= 1.96\text{-}3.45$) وجود نداشت. به طور کلی، اگر چه خطر سدیمی شدن در استفاده از ماده شیمیایی بی کربنات سدیم دیده نشد اما استفاده از آن باید با جانب احتیاط همراه باشد.