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EFFECTS OF ROCK FRAGMENT ARCHITECTURE ON SOME SELECTED SOIL PROPERTIES IN A SEMIARID ENVIRONMENT

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Abstract

Stony soils cover a large portion of the Iraqi territory, particularly, the hilly and mountainous areas of Iraqi Kurdistan Region. Albeit they are abundant, their properties are not well recognized. Accordingly, minilysimeter and repacked plot experiments were conducted under open air at Sumail site-Duhok governorate –Kurdistan regions. The main objectives were to study the architectural effect of rock fragments size, content and cover on topsoil water conservation, surface soil temperature and infiltration rate. In each experiment the study factors were two types of soil, different soil rock content/cover and different rock fragment size. The results of the minilysimeter experiment signified that with a few exceptions, the retained soil water content over time under a rock cover of 40% was superior to those under control and under a rock cover of 20% for the same rock size. There are also indications that the effectiveness of rock cover in controlling evaporation decreases with an increase in rock size. The soil temperature under rock mulching was lower than that of the control by 0.5 to about 2.5 oC depending on the treatment combination. The results of the repacked plots also revealed that the infiltration rate increased with increasing rock content up to 30% and began to decline beyond this level. The 2–4.75 mm rock fragment treatment offered the highest average or basic infiltration rate compared with the other sizes under the same level of soil rock fragment content.

Keywords: Stony Soils, Rock Fragments, Topsoil Water Conservation, Infiltration Rate

1. INTRODUCTION

Approximately 60% of the Mediterranean region is covered by soils containing a significant fraction of rock fragments (soil with rocks) (Poesen and Lavee, 1994). These soils are mostly situated in mountainous and forested lands. The rock fragments can be defined as particles having diameters of equal or more than 2 mm (Poesen, 1994). According to Poesen and Lavee (1994), rock fragments can be classified based on their size into: pebbles ranged 2-75 mm, cobbles 75 to 250 mm, stones 250-600 mm and boulders more than 600 mm. They also reported that the rock fragments have a multifunctional effect on protecting hilly areas from degradation. For example, cobbles can enhance soil moisture conservation under moderate water stress state. In general, mulching the soil surface with rock fragments or other materials can improve the soil conditions, such as temperature, moisture and available nutrients (Truax and Gagnon, 1993; Guo et al., 2010). The size, cover, content, shape, geological origin, and degree of weathering of rock fragments can affect soil hydrophysical properties, particularly soil retention capacity and hydraulic conductivity. (Hlavacikova et al., 2015). Jimenez et al. (2017) observed that applying cover of rock fragment and straw mulch altered the temporal and spatial distribution pattern of soil moisture content within the soil profile. Furthermore, they reported that rock fragment cover is better suited for small seedlings with shallower initial roots, as well

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as Pinus and other conifer species with superficial root systems. Numerous researchers have observed that decreased runoff, lower soil temperature, and lower evaporation under lithic mulches such as gravels, pebbles, and so on can be attributed to capillarity disruption (Zhang et al.,2016).

Zhu and Shao (2006) reported that the presence of stones in soil profile can alter some physical properties of soil, for instance, the number of macropores water cross-section, and mechanical properties of soils. Kosmas et al. (1993) concluded from the comparison of crop production under soil with and without rock fragments that rock fragments tended to decrease soil evaporation. Zhongjie et al. (2008) discovered that soil evaporation decreased with increasing soil rock content (0-20%), and that soil evaporation became stable beyond the upper limit of this range. Jimenez et al. (2017) revealed the rock fragments enhanced soil moisture only at depth 10 and 20 cm compared with the soil without rock. In contrast, they caused reduction the water storage below these depths. The increased soil - moisture content under the mulch layer can be mainly linked to reduced temperature (Rhoades et. al., 2012).

However, Zhang et al. (2016) highlighted that rock fragments can regulate temperature of soil, and soils with stones warm faster than soils without rocks with increasing temperatures, but when the soil temperature starts to drop, the temperature of such type of soil stays high for a long period of time (Poesen and Lavee, 1994). This implies that it acts as a buffer against abrupt change in temperature. Their findings also indicated an increasing in rock fragment content is beneficial to soil water storage and circulation, as well as nutrient accumulation, up to a certain point. Lv et. al. (2019) investigated the effect of different fragment contents in the range of (0-60%) and rock sizes, namely, (1-4; 4-7 and 7-10 cm) on hydrological processes. they observed that as content of rock fragment increased, runoff rates decreased, and the classes of size 4-7 cm having the greatest reduction effect. This may have appositive effect of soil water storage. Katra et al. (2007) focused on the progression of top soil water content under rock fragments after rainfall storms and discovered that large rock fragments are favorable micro-environments for accepting and retaining rain water and overland flowing water. Xie et al. (2010) studied the effect of the particle sizes, (0.3-1, 1-2 and 2-6 cm) on soil temperature (ST) and discovered that soil temperature decreased as the particle size increased as a result of porosity enlarging.

Regarding the influence of rock properties on rate of water movement into and within the soil, Hlavacikova et al (2015) reported that rock fragments in the soils reduce the effective cross-sectional area available for flows of water. WU et al. (2021) observed a steady decrease in infiltration rate with an increase soil rock fragments content from 0 to 40%. Meanwhile, the effect of rock size was not obvious on soil hydraulic properties. In contrast, previous studies unveiled that the impact of large rock fragments was more profound on reducing relative effective saturated hydraulic conductivity (Novák et al. 2011). On the other hand, it was discovered that as volumetric content of rock fragment increased, the steady infiltration rate increased until it reached a range of (15% to 20%). Beyond this range it tended to drop with further increase in soil the rock fragment content (Zhongjie et al., 2008). In a similar study, Zhang et al. (2008) observed that for fine earth with same bulk density the presence rock fragments in the range of 10-20% can increase rate of infiltration; but, further increase in rock

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fragments will cause a decrease in the rate of this parameter. As there are limited studies on hydraulic and other soil properties of rocky soils, this study was initiated to 1) study the impact of rock fragment architecture (cover, content and size) on soil hydraulic properties and surface soil temperature 2) define the range over which infiltrate rate increases by increasing soil rock fragment content.

2. MATERIALS AND METHODS

2.1. Minilysimeter Experiment

2.1.1 Preparations

Two different sites were selected for soil sampling, viz, Sumail and Durabon, to obtain two levels of clay content (37 and 52.6%) respectively. The soils are representing the dominant soil textural classes in the wide plains of Duhok. Soil sample were taken from the surface layer (0.0-0.30m) of these two sites. Upon bringing representative samples to the experimental site, they were air dried, ground gently to pass through a sieve (4.75 mm), thoroughly mixed and kept until use. Table 1. describes some selected physical and chemical properties of the two base soils.

Table1: Some selected physical and chemical properties of the soils used in experiments

Property		Unit	Average measured values	
			T1	T2
Particle size distribution	Clay	g kg^{1}	526	370
	Silt	g kg^{1}	400	400
	Sand	g kg^{1}	74	230
	Textural Name	-	Silty Clay	Clay Loam
Soil bulk Density		Mg m^{-3}	1.37	1.38
pH		-	7.95	8.40
EC		dSm^{-1}	0.22	0.56
Organic Matter		g kg^{-1}	10.29	17.73
Calcium carbonate equivalent		g kg^{-1}	166.20	354.29
Field capacity		(%)	33.66	25.60
Wilting point		(%)	24.13	17.17

Before initiating the experiment, 54 galvanized cylindrical tanks with handles were constructed, each having a 30 cm diameter and a 30 cm height. Prior to embedding the soil columns in the ground, 54cylindrical pits were excavated in form of three rows (blocks), each having 16 pits. The spacing between two minilysimeters in the same row was 0.5 m, while row spacing was 1 m. The excavation depth was 30 cm, but their diameters were slightly larger than 30 cm to allow to install the column easily.

The sieved soil sample from each site was subdivided into portions. The soil water content of each portion was raised to optimum water content by spraying with tap water. Then the minilysimeters were packed with predetermined quantity of each soil at optimum moisture content to attain nearly the insitu soil densities. Compaction was performed in form of 3 layers,

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each 0.1 m in thickness using a wooden hammer constructed for this purpose. They were compacted to insitu densities of 1.38 and 1.30 Mgm-3 respectively. After soil, packing, predetermined quantities of rocks fragments were spread over the soil surface to give the indicted percentage of coverage for each size. Table.2. describes some properties of the rock's fragments. Before experimentation, soil thermometers were also installed at a 5 cm depth below the surface soil.

Table 2: Some Properties of Selected Rocks Fragments

Name	Type of rock	Chemical composition	Texture	Color	Absorption %	Fragment shape
Dolomite	Sedimentary rock	$CaCO_3$, $MgCO_3$	Sugary texture	White to yellow	1.920	Irregular

2.1.2. Experimental Design

The design of the experiment was factorial in RCBD with three factors in triplicate. The factors were type of soil (T); rock fragment coverage (P) and rock fragment size(S). The factors encompassed the following levels:

T= type of soil with two level: T1= Sumail soil clay content=52.6%), T2= Durabon soil (clay content=37%);

S = Rock fragment size: S1= 5 – 20 mm; S2= 20 – 75 mm; S3= 75 – 250 mm

P=Rock coverage: P1= 0%, control; P2 =20%; P3=40%

The number of treatment combinations was 2x3x3=18 and the number of experimental units became 18x3=54

2.1.3 Measurements of Soil Water Content and Soil Temperature over Time

Before starting measurement, soil water content was brought to field capacity and exposed to open air condition as the first cycle of wetting. The loss in soil moisture was monitored gravimetrically by weighing the column using a balance having the precision of 10 mg. The columns were weighed at small time intervals at the beginning of each cycle and at less frequent interval thereafter. The measurements were repeated for additional three cycles. The soil temperature was also measured periodically under each treatment in duplicate. The experiment was run over a period of days between May 23th and October 2nd 2021.

2.2. Repacked Pit experiments

2.2.1. Location

This experiment was initiated during the summer season of 2021/2022. It was conducted on a nearly level piece of land at Sumail site (N36° 03′40″ , E44° 03′38″ , altitude = 415 m amsl).

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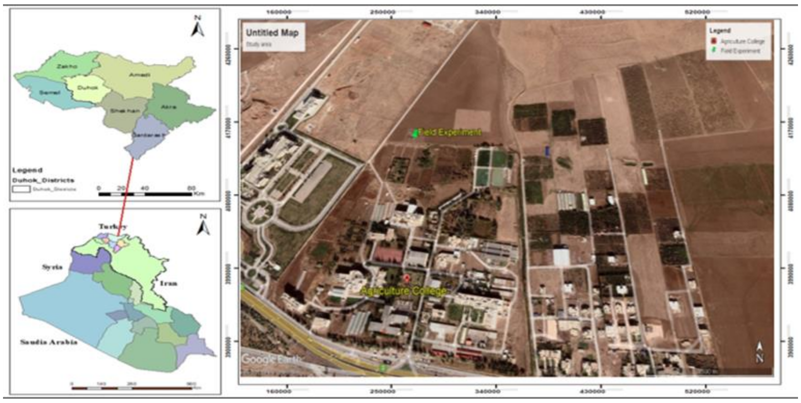
Figure 1: Location map of the study area



2.2.2. Experimental Setup

An area of about 50 m x 50 m was selected at Sumail site for this purpose. Before delineating the experiment layout, a rough grading was performed with a minimum disturbance through removing abnormalities and filling minor depressions and removal of vegetation cover. Afterwards, the field was subdivided into two blocks and each block was subdivided into 32 plots in form of two lines. The plot dimensions were 1 m x 1m and separated with a buffer zone of 1.5 m2. The distance between the blocks was 3.5 m. At the center of each plot a pit 1.0 m wide, 1.0m long and 0.6 m deep was dug out manually with a pickaxe and the excavated layers were laid in sequence. Prior to backfilling, the excavated materials of each layer were air dried, ground to pass through a 4-mm sieve and its water content was brought to an optimum water content of 18%. Deraboon soil was used as second filling material. The soil materials were backfilled to approximately the same insitu density after incorporating the correct amount of rock fragment. At the end of backfilling the soils of the plots were subjected to three cycles of wetting and drying from end of June to mid of August to restore its natural structures partially.

2.2.3. Experimental Design

The impact of three factors or variables was studied on soil infiltration rate. The first factor was rock fragment content (L) and encompasses the following levels:

L1= Control (without rock fragments), L2= 15%, L3= 30% and L4 = 45%

The second factor was rock size. Rock fragments with diameters of 2.00-4.75 mm, 4.75–20 mm, 20-75 mm and 75 -250 mm were selected in this experiment. The third factor was type of soil, namely Derabon soil (clay=37%) and Sumail soil (clay=52.6%) Predetermined quantity of each size was mixed with each of the two base soils to give different soil rock contents. The third factor was type of soil (Sumail and Derabon).

2.2.4. Infiltration Measurement

The backfilled soils were subjected to three cycles of wetting and drying. At the end of the third drying cycle and before initiating infiltration tests the depth, length and width of cracks were measured in each plot according to the method outline by (Zain Abideen, A and G.H

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Robinson., 1971). The double ring infiltrometer method as described by Micheal (1978) was followed to measure the infiltration rate and depth of infiltrated water as influenced by content and size of rock fragments and type of soil. Both rings were driven into the soil to a depth of about 8 cm. Care was taken to allow Centrical positioning. Before pouring water into the rings, a piece of nylon sheet was placed over the soil surface to prevent pudding and sealing of the soil surface. Furthermore, a plastic ruler was inserted into the soil adjacent to the inside side of the inner ring for recording water level. Time was recorded and the volume of water required to maintain a water depth of about 7 cm in the inner ring was measured. The test was continued until steady state infiltration rate was reached.

3. RESULTS AND DISCUSSION

3.1. The Impact of Rock Features on Soil Water Conservation

Figs. 2through 5 display the variation of average soil water content of the minilysimeters packed with Sumail (T1) and Derabun (T2) soils over time as affected by rock fragment cover and size. The soil water content of soil was brought to field capacity and subjected to evaporation in open air. The procedure was repeated four times during the late spring to the early autumn seasons of 2021. The drying period ranged from one to two weeks. Overall, the evaporation process under rock fragment was more stable as compared with that from bare.

It can be also observed that the soil water content linearly correlated with time during the first cycle of drying (from 30/7 to 10/8/2021). The low external evaportivity may be responsible for such relationship. In contrast the soil water content during the remaining drying cycles dropped rapidly during the first three days and tends to diminish slowly beyond this point. With a few exceptions, the retained soil water content under a rock cover of 40% was superior to those under control and under a rock cover of 20% with the same rock size. The bare soil surface is exposed to wind and solar radiation during the drying period. By contrast, when the soil surface is covered with sufficient quantity of rock fragments, the soil under the rock fragments is sheltered. However, on the whole, the percent of increase in water content under the highest cover level ranged from about 1.8 to 3.6% on volume basis. This highlights that the percentage of coverage should be increased to reduce the frequency and the depth of applied water, particularly in case of tree seedlings in reforestation program and establishing city gardens.

The results also indicated that there is no a steady increase in conserved soil water content with an increase rock fragment cover. For instance, the soil water content with the same rock size under control (bare soil) was higher than that under a 20% rock cover.

It is note worthing to mention that during all the four cycles of drying the soil moisture content under the bare soil exceeded that of 20% rock cover when the rock size was in the range of 4.75 to 20 mm.

There are also indications that the effectiveness of rock cover in controlling evaporation decreases with an increase in rock size. Further, the size of rock 4.75 to 20 mm offered the highest performance compared with the other two sizes. This result is not in concordance with the finding of Yuan et al. (2009), who observed that the evaporation suppression was intimately

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correlated with gravel size. The large particle size has power to retard evaporation. The very large pores of the gravel mulch with large fragments are the most suitable plausible explanation for their relative effectiveness. Upon wind blowing across the soil surface, turbulence and convection can occur within the large pores of the rock fragments. This finding also supports the results of Hayder (2004), who observed that the effectiveness of gravel size on evaporation suppression was reduced with increasing gravel size.

A close inspection of Figs.2 through 5 indicates the effect of rock features on evaporation reduction in Sumail soil is more prominent that those under the Derabon soil.

Figure 2: Soil moisture loss from the study soil over time as influenced by rock fragments size and cover during the period from 30 / 7 / 2021 to 10 / 8/ 2021

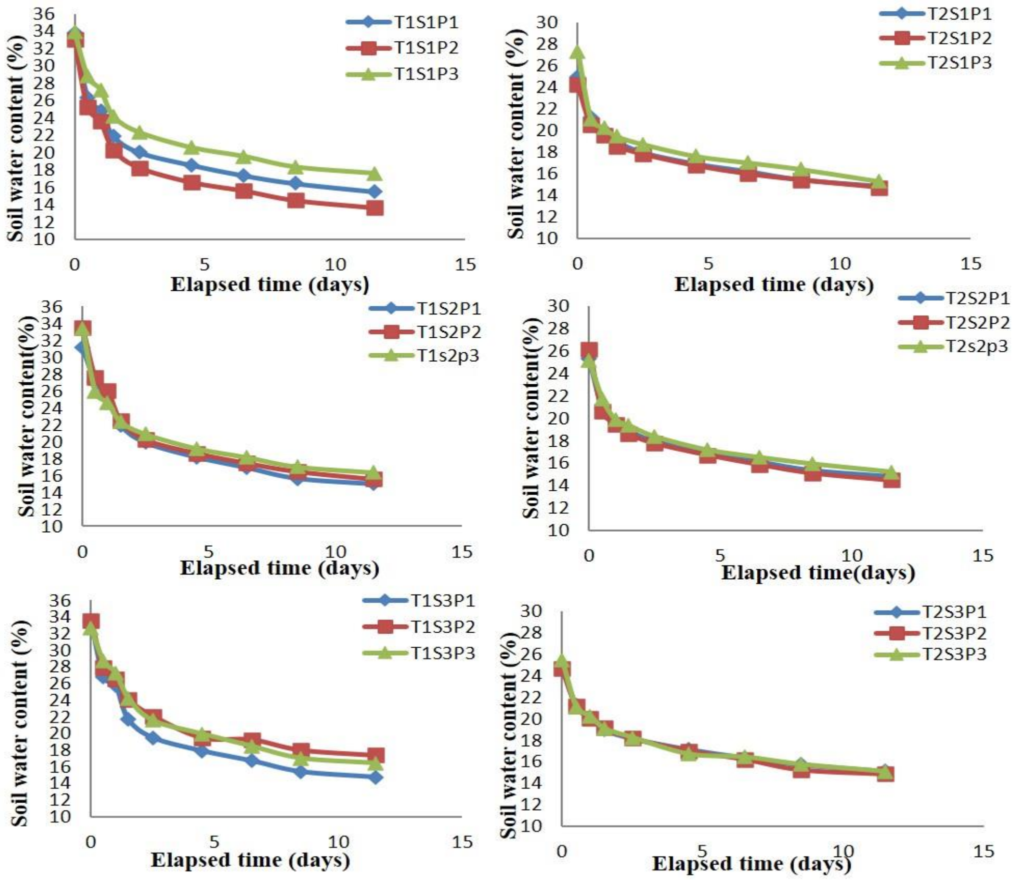

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Figure 3: Soil moisture loss from the study soil over time as affected by rock fragments cover and size during the period from 31 / 8 /2021 to 13 / 9/ 2021

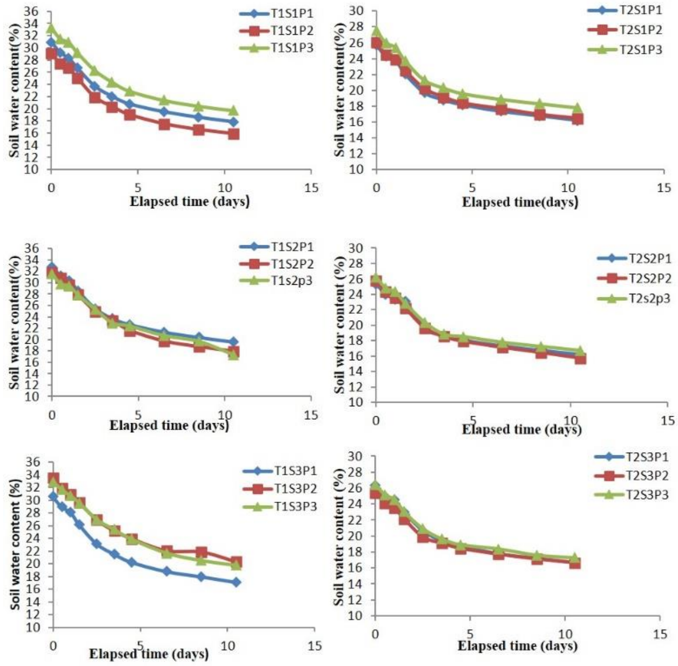

Figure 4: Soil moisture loss from the study soil over time as affected by rock fragments cover and size during the period from 1 / 10 / 2021 to 14 / 10/ 2021

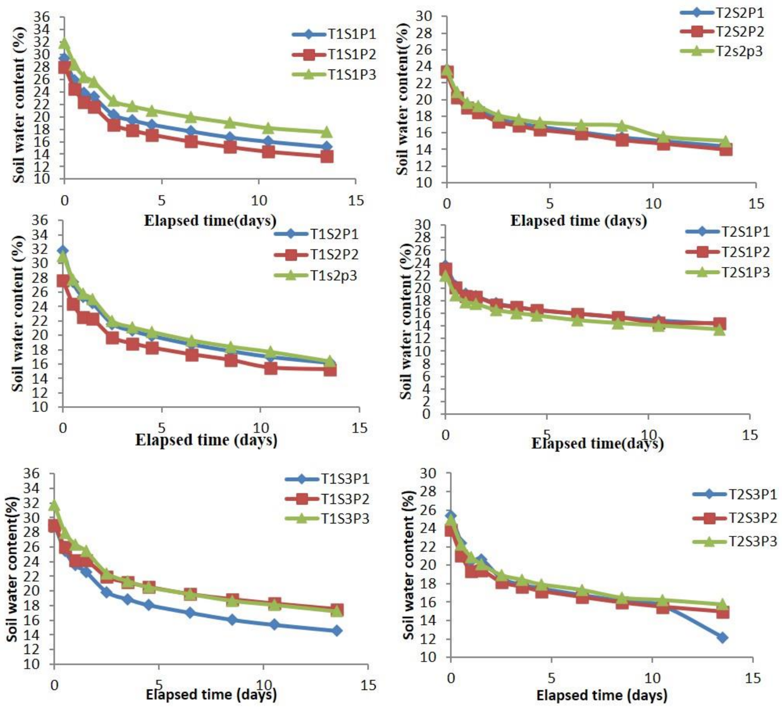

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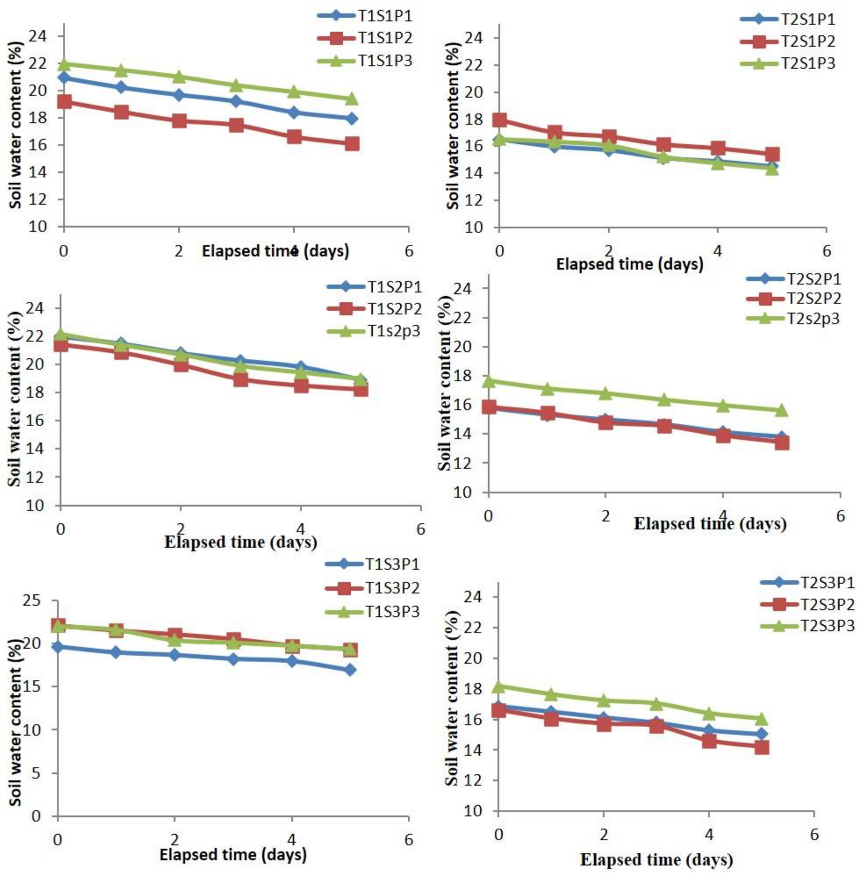
Figure 5: Soil moisture loss from the study soil over time as affected by rock fragments cover and size during the period from 9 / 5 / 2022 to 15 / 5/ 2022



3.2. The Impact of Rock Features on Soil Surface Temperature

Fig.6 presents the effect of rock fragment features, namely cover and size on soil temperature recorded at a 5 cm depth below the surface of soil in Sumail and Derabun soils during the drying cycles that were implemented between May and the mid of October 2021. Overall, the results indicated that the soil temperature tended to decrease with an increase in percentage of rock coverage from 0 to 40%. The soil temperature under rock mulching was lower than that of the control by 0.5 to about 2.5 ^{o}C depending on the treatment combination. The effectiveness of rock cover on reducing soil temperature is more profound in the Sumail soil. The result of this study is in line with the finding of Lightfoot (1995) who reported that a lithic mulch increases surface roughness, generating more turbulent air flow over the garden surface. This causes reducing the hottest day-time temperatures and raising the lowest nighttime temperatures. As a result, a more thermally stable and healthy environment is provided. With regard to lithic mulches like gravels, pebbles and cobbles can lower soil temperature, and lower evaporation due to the disruption of capillarity (Zhang et al., 2016). One the other hand, Katra et al. (2007) reported that like the soil under shrubs, the soil under rock fragments is subjected to microclimatic conditions of relatively moderate soil temperatures compared to unvegetated

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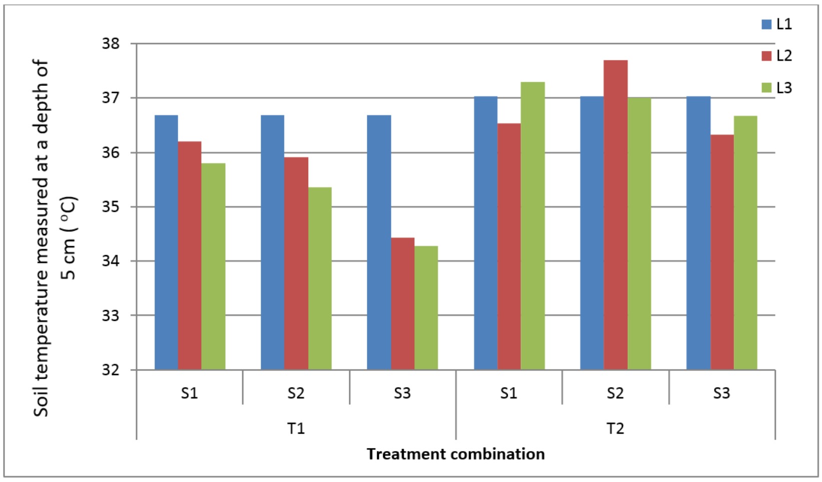
soil. In contrast to the obtained results from this study, other researchers pointed to contrasting results.

Unlike the Sumail soil, the Derabun soil did not exhibit an obvious trend. It can also be elucidated from Fig.6. that the impact of increasing on stones size on lowering soil temperature is not obvious under most of the applied treatments. Unlike the obtained results from this study Haydar (2004) observed that the effectiveness decreased with increasing rock particle diameter under the situation of full coverage.

Figure 6: soil temperatures at a 5 cm depth below the soil surface of the study soils as affected by rock fragments (cover and size)



3.3 Infiltration Characteristics as Affected by Some Selected Rock Features

The effect of different rock fragment contents (0%, 15%, 30%, and 45%) and rock fragment sizes (4.75 -20, 20 -75 and 75- 250 mm) on average infiltration rate during a period of 3 hours for the plots with repacked Sumail soil is shown in Fig.7. It is evident from Fig. 7 that under the same rock size. The average infiltration rate increased with an increase in soil rock fragment content up to 30% and thereafter it started to drop with further increase in soil rock fragment content. An increase in infiltration rate with increasing rock fragment content in the range of 0 – 30% stems from the fact that the space between the rock fragments is not completely filled with fine earth or to development of temporary lacunar pores which can give rise to preferential flow (zhongjie et al. 2008; Nasri et al., 2015). An increase in the rock fragment content gives rise to increased flow tortuosity (Hlaváčiková et al. 2016). By contrast the decrease in average infiltration rate with further increase in rock fragment content beyond 30% may be due to substantial reduction in cross-sectional area available for flow.

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Figure 7: Average infiltration rate of tow soils as affected by rock fragments cover and size

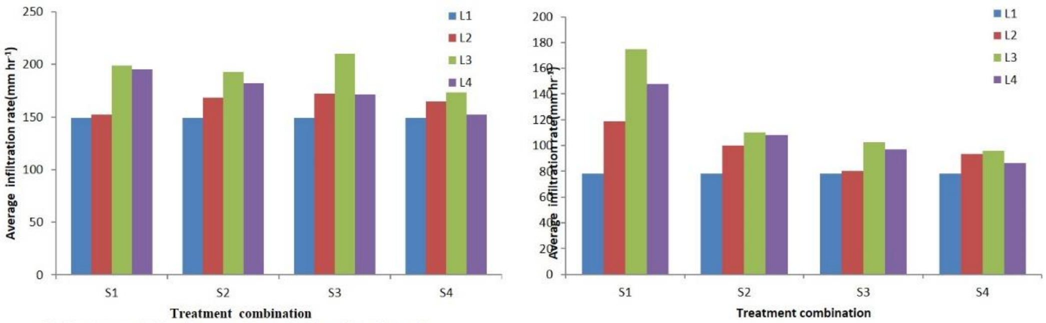

Fig.7-a.Average infiltration rate of Sumail soil as affected by rock fragments cover and size

Fig.7-b.Average infiltration rate of Derabun soil as affected by rock fragments cover and size

The steady state (basic infiltration rate) exhibited similar trends to the average infiltration rate. This implies that the steady-state infiltration rate increased with an increase in rock fragment content under the same rock fragment size in most cases (Fig.8). Wu et al., 2021 reported that the impact of rock fragments on soil hydraulic properties are inconsistent under different soil and climatic conditions, either causing reduced infiltration or the opposite effects.

Figure 8: Basic infiltration rate of used soils as affected by rock fragments cover and size

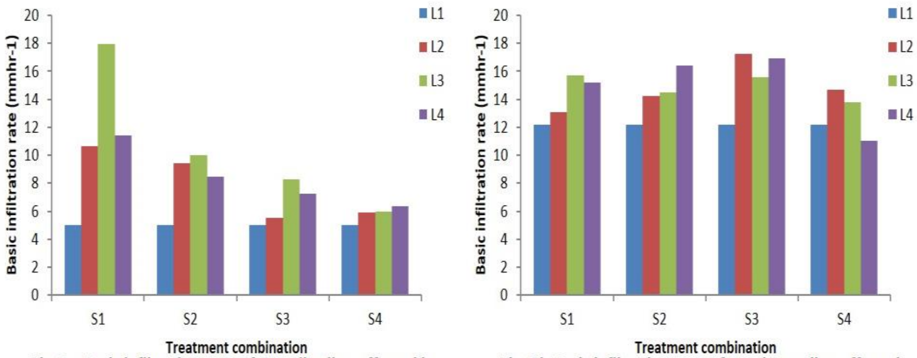

Fig.8-a.Basic infiltration rate of Sumail soil as affected by rock fragments cover and size

Fig.8-b.Basic infiltration rate of Derabun soil as affected by rock fragments cover and size

It is noteworthy to mention that different, and even contrasting results, have been observed for the relationship between infiltration characteristic and rock fragments content. Wu et al. (2021) have noticed that the infiltration rates over time decreased with an increasing rock fragment content to an observed minimum value for a 40% rock fragment content. However, the obtained results during this study were in accordance with most of the published data in literature. For instance, Zhongjie et al., 2008 observed that the steady infiltration rate increased with increasing volumetric content of rock fragments until it reaches the range of 15–20%, and then it started to decline when the rock fragment content exceeds this limit.

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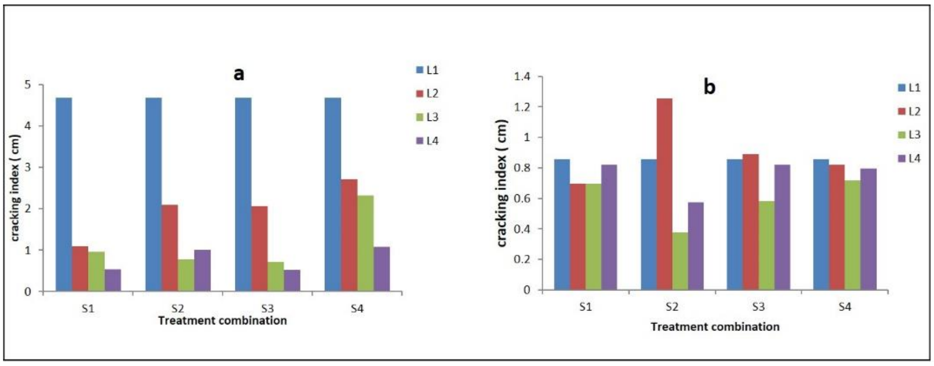
As compared with the Sumail soil, the Derabun soil offered the higher average or basic infiltration rated under the same treatment combination. The lower clay content of the Derabun soil may be responsible for its superiority.

Upon replotting Figs. 7 through 8, it was discerned that the average and basic infiltration rates tend to decrease with an increase in fragment size. The 2–4.75 mm rock fragment treatment offered the highest average or basic infiltration rate compared with the other sizes under the same level of soil rock fragment content. These results support findings of Guo et al. (2010), who found that solute transport was higher in soil with small rock fragments. In a similar study, it was observed that the infiltration rates have the trend of decreasing with increasing soil depths when the volumetric content of rock fragments with bigger size increases (Zhongjie et al., 2008).

Figs 9a and b portray the cracking index (or the volume water required for initial ponding) for the Sumail and Derabun soil affected by rock fragment content and size. The plotted data in Figs. 9 revealed that there was a gradual decrease in cracking index with an increase the rock fragment content in the Sumail soil. By contrast, the effect of increasing rock fragment content on cracking is not obvious on this parameter (Fig.9). The difference in behavior of these two soils stems from the fact that the Sumail soil exhibits a higher swell-shrink potential compared with the Derabun soil. Additionally, it is apparent from Figs. 9a and b the effect of rock size on modifying cracking index is not obvious, particularly in the in the Derabun soil.

Figure 9: Cracking index as affected by interaction between rock cover percentage and rock fragments size a= Sumail soil b= Derabun soil



The results also showed that Kostiacov model gave the best fit for the relationship between cumulative depth of infiltrated water and time (not shown here) and more than 98% of variation in accumulated depth was explained by time in most cases.

The ANOVA test revealed that the infiltration rate and the soil temperature were significantly ($P \leq 0.05$) affected by both rock fragment level and rock size and the interaction among them.

4. CONCLUSIONS

It can be inferred from the results of the study that there is no a monotonic relationship between level of rock fragment cover or content and each of conserved soil water, soil temperature and

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the infiltration rate. To conserve soil water, the percentage of coverage should be more than 20%. Additionally, the rock fragment size of 2 - 4.75 mm was the most effective size for suppressing evaporation at the highest percent of rock cover. The results also indicated that the rock fragment content began to reduce infiltration rate when its percentage exceeded 30%.

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