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Full length article

Developing rainwater harvesting methods under sloping areas conditions in Wadi El-Raml - Northwest Coast - Egypt

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ABSTRACT

New methods and earthen practices for rain-runoff water harvesting under sloping areas conditions to transform it from catchment areas into targeted areas at the same site and time to maximize the benefit from water runoff and store it in the same area for future cultivation to raise the productivity of water harvesting and optimal exploitation of a unit area by dividing these areas into several micro-catchment areas which were formed in different shapes by creating earthen barriers. The field experiment was applied at Wadi El Raml, Matrouh Governorate in the winter season of 2022/2023 under the following treatments: - three slopes (5, 8 and 13%) - (normal and compacted catchment area) and two shapes of micro catchments (W and reciprocal triangles). The results showed that treatment T_{11} which comprised a high slop of 13% with compacted catchment area and W shape for the divided micro-catchment achieved the highest values of runoff 7.7 mm, runoff productivity 32.39 $m^3.fed^{-1}$ and water saving 279 $L.tree^{-1}$ respectively, While traditional treatment T_0 and T_2 which comprised the low slope of 5% with normal catchment area and triangle shape recorded the lowest values. In general, compacting high slope catchment areas and dividing them into micro catchments increases the productivity of water runoff harvesting and water saving for the target area.

1. Introduction

In light of the current climate changes and the exposure to water scarcity and drought, rainwater is considered the primary source of agriculture and irrigation in arid and semi-arid areas. Drought and water scarcity are one of the most important factors that affect agricultural development in arid and semi-arid regions, (Laura et al., 2008). Water harvesting and maximizing its use is a basic pillar of saving water and confronting its scarcity. Egypt has limited water resources, and it will become water scarce within a few decades. Rain harvesting is one solution, particularly on the North Coast of the Mediterranean Sea and Red Sea (Abdel-Shafy and El-Saharty, 2015). Zaghloul (2013) showed that the fundamental factors contributing to Egypt's food security challenges are the rapidly growing population, the availability of agricultural land, and the restricted water resources. Abdel-Shafy et al. (2010) stated that water harvesting plays a significant role in increasing water resources on the north coast of Egypt, which can enhance agriculture's livestock production. Improvement in the arid and semiarid regions of the country by collecting surface runoff during excess rainfall markedly decreases the risk involved in rain-fed agriculture, helping in restoring self and sufficiency in food production. The sloping areas in the valleys cause irregular surface runoff of rainwater, which causes the loss of a large portion of the water without benefiting from it, carrying with it some sediments resulting from water erosion. Likewise, the sloping areas are considered by many humans to be areas for surface runoff only, without considering them as target areas for agriculture. Wu et al. (2010) mentioned that practices that reduce slope runoff would also help reduce soil erosion and may help to reduce the impacts of drought. Zhang et al. (2013) illustrated that, micro catchments have relatively small runoff generation areas (from dozens to a hundred sq.m) and are cheap and simple to implement their collection

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area is usually a small depression located near the runoff generating area, in which one or a few trees/shrubs may be planted due to the short overland flow path runoff generation is efficient and even short low-intensity storms may generate. Zhang et al. (2015) illustrated that the important and urgent problems for the soils are how to effectively protect and use water and soil resources, improve water use efficiency, and adopt appropriate practices for the sloping farmland. Ahmed (2005) stated that agricultural land may be graded and divided into basins for storing enough water to allow enough water to be stored for the season. Alemu and Kidane (2014) improved in-field water harvesting can increase the time required for crop moisture stress to set in and thus result in improved agricultural productivity, Water is a major and necessary factor for environmental development. Jourgholami et al. (2017) reported that if the main catchment area is divided into a small catchment area, this will support increasing runoff rapidly. Zidan and Dawoud (2013) reported that a technique of runoff collection known as runoff harvesting may be used for food and water production. Different practices on soil surface support increasing runoff and decreasing the soil infiltration rate. Umer et al. (2019) mentioned that the compaction of the soil decreased the infiltration capacity and increased the inundation depth and duration of flow. The infiltration capacities of many soil surfaces in cities have decreased during the developmental process because of compaction **(**Pitt et al., 2008**).** Soil micro-topography with a shortened runoff path and enhanced localized interception and infiltration of precipitation increases the soil water content, thereby improving soil water conditions for vegetative growth (Wu, 2006). So, this research aims to enhance the role of sloping areas in harvesting runoff water above them and also consider them a target area where water can be directed and retained in places where trees can be planted in the future. This is done through new practices and methods of small catchment forms on lands with a tendency to harvest and store runoff water to maximize runoff water harvesting rate and productivity and increase soil water saving in the part targeted for agriculture, these practices will be applied under a sloping area by dividing it into a small micro catchment and compacting them to decrease the infiltrating rate.

2. Materials and methods

2.1. Experimental site description

The field experiment was carried out at Wadi El-Raml, Northwest coastal zone, Matrouh, Egypt, (Latitude: 31 15\ 35\ \, N) and (Longitude: 27 09\ 43\ \, E). during the winter season of 2022.The soil texture was sandy loam. Different practices applied as a treatment as followed: catchment slopes of (5%,8% and 13%), (normal catchment-compacted catchment). and divided catchment areas into micro catchments through two shapes (W) and (recursive reciprocal triangles). Treatments were arranged in a randomized block design with three replicates for each treatment. The area of every replicate was 2160 m^2 (72×30m), which comprised 12 treatments; every treatment was (6×30 m) as shown in Fig. 1.

2.2. Field experiment treatments

- T_0: Traditional treatment (normal sloping area with non-practices)
- T_1: 5 % slop of catchment + normal catchment area + W shape
- T_2: 5 % slop of catchment + normal catchment area + triangles shape
- T_3: 5 % slop of catchment + compacted catchment area + W shape
- T_4: 5 % slop of catchment + compacted catchment area + triangles shape
- T_5: 8 % slop of catchment + normal catchment area + W shape
- T_6: 8 % slop of catchment + normal catchment area + triangles shape
- T_7: 8 % slop of catchment + compacted catchment area + W shape
- T_8: 8 % slop of catchment + compacted catchment area + triangles shape
- T_9: 13 % slop of catchment + normal catchment area + W shape
- T_{10} :13 % slop of catchment + normal catchment area + triangles shape
- T_{11}: 13 % slop of catchment + compacted catchment area + W shape
- T_{12}: 13 % slop of catchment + compacted catchment area + triangles shape.

2.3. Soil infiltration rate

A heavy roller machine weight 400kg attached to the tractor was used for compacting soil surface of the catchment area through one pass. For the normal and compacted catchment area, the soil infiltration rate was measured using the double-ring method according to the following equation (Philip, 1957).

$$IR = \frac{F}{T} \quad \text{... [1]}$$

where:

IR = infiltration rate, cm.h^{-1};
T = time, h; and
F = cumulative water depth, cm.

2.4. Rainfall amount

By a digital automatic rainfall gauge, the rainfall amount for each storm during the winter season 2022-2023 was recorded.

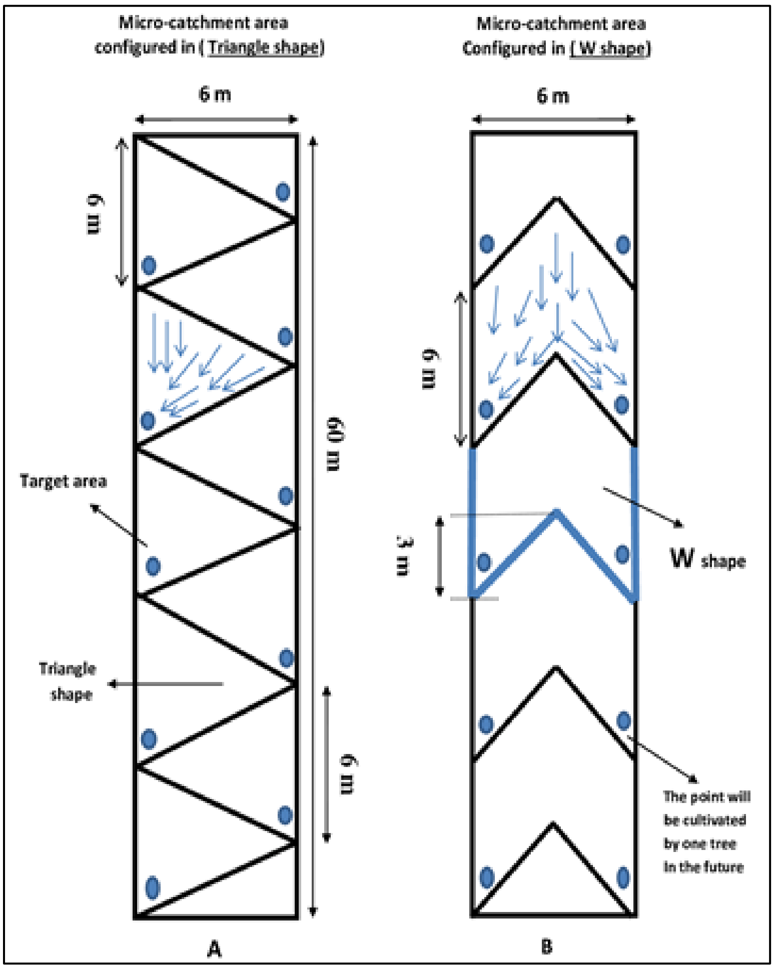

Fig.1. Indicate the triangle and W shape as a micro-catchment.

2.5. Runoff rate

Runoff rate for every treatment was measured after every storm by a runoff gauge instrument (Morgan 1995) which was installed at the down-slope edge of different treatments, Runoff depth was measured at each collected water runoff by a graduated cylinder.

2.6. Soil moisture content

After 12 hours of each effective rainstorm, soil samples were taken from soil depths (0-40cm) for measuring moisture content by the gravimetric method. It was calculated through the following equation:

$$MC = \frac{W_w - W_d}{W_w} \times 100 \quad \text{... [2]}$$

where:

MC = soil moisture content (weight %);
W_w = wet soil mass (g); and
W_d = dry soil mass (g).

2.7. Runoff water harvesting productivity

Water harvesting productivity was calculated as runoff per cubic meter generated from catchment equal to one feddan; every one mm of runoff is equal to 4.2 cubic meters (Oweis and Taimeh, 1996):

$$RWP = \frac{R_V \times 4200}{1000} \quad \text{... [3]}$$

where:

RWP = runoff water productivity, $m^3.fed^{-1}$; and
R_v = runoff water generated (mm) from the catchment area, one feddan

2.8. Runoff Water saving for every tree

According to the sloping area of one feddan, which is 4200m^2 and divided into small micro-catchments with an area of 36 m^2 for everyone that will be cultivated by one tree, water saving for every tree was calculated according to the total water harvesting productivity per feddan, which comprised 166 micro-catchment areas.

$$WS = \frac{RWP}{166 \times 1000} \quad \text{... [4]}$$

where

WS = water saving for every tree, or every micro-catchment area, $L.tree^{-1}$;
RWP = runoff water productivity, $m^3.fed^{-1}$;
166 = number of micro-catchment areas in one feddan; and
1000 = to convert a cubic meter to a liter.

3. Results and discussions

3.1. Soil infiltration rate

A heavy roller machine was used for compacting the catchment area. The soil infiltration rate was tested for normal and compacted soil, which recorded 11.40 and 10.18 mm h1, respectively. The compacted catchment area recorded the lowest values of infiltration rate. This is attributed to the compressing process, which increased the convergence of soil particles and decreased both the disintegration of the surface soil layer and porosity, making it semi-insulating, which caused an increase in soil solidarity and a decrease in soil infiltration rate compared to the normal catchment area.

3.2. Rainfall amount

The monthly rainfall data are illustrated in Fig. 2. Rainfall events during the winter season of 2022 occurred from October 2022 to April 2023. Total rainfall reached 127.6mm. The difference in monthly rainfall was observed. January and February recorded the highest storms, which were 27 and 31 mm, respectively. Minimum storms were 11 and 17.3 mm, which occurred in October and March, respectively, while April was a rainless period.

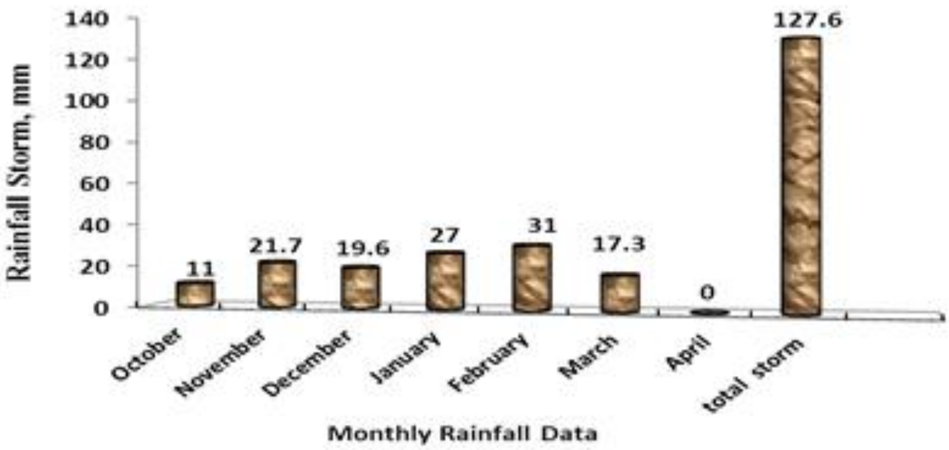

Fig. 2. Rainfall data during the winter season, 2022.

3.3. Effect of different treatments on runoff rate

The effect of different runoff water harvesting treatments on total runoff was shown in Fig. 3. Data illustrated that increasing catchment slope with high rainfall storms increased runoff rates, and the micro-catchment, which was configured in shape W was better than a triangle shape. Treatment T_{11} generated the highest runoff rate, 7.71mm, while T_0 and T_2 recorded the lowest values of 2.56 and 4.62 mm. Under the same slopes, the effect of the compacted catchment area on increasing runoff rate was observed in comparison with the normal catchment area, thus $T_{12} > T_{10}$ and $T_{11} > T_9$ Also, the effect of micro-catchment shape was observed under all treatments, so $T_{11} > T_{12}$ in the case of the compacted catchment area and $T_9 > T_{10}$ in the case of the normal catchment area. The lowest values recorded for treatments T_1 and T_2 were 5 and 4.62, respectively, with the lowest slope of 5% and normal catchment area. In general, the three factors affected by the increasing runoff rate were the sloping, compacted soil, and the applied W-shaped earthen practices. This is due to the fact that the compaction of the catchment area reduced the porosity and permeability of the soil, which helped reduce the infiltration rate and increase water flow in the same direction of slope (Nicholson, 2011). The longer time of runoff flow in the largest catchment with a high slope induces more losses by leaching and turbulent flow (Khan et al., 2016). So, dividing the catchment into mini catchments decreases the flow path and then decreases the duration of soil leaching, especially with the W shape, which received rainwater. runoff in the same direction of slope and gravity, which generated balanced flow, and in a vice versa triangle shape, which generated turbulent flow.

3.4. Soil moisture content

At a soil depth of 0–30 cm, the soil moisture content in the target area for all treatments and rainfall storms were shown in Fig. 4. Data showed that the treatment (T_{11}) compacted catchment area with the W shape of a micro-catchment area machine and the high slop of 13% achieved the highest value of total soil moisture content, 43.6%, while T_2 and T_0 recorded the lowest values of 26.2 and 14.5%, respectively. On the other hand, the high slope with the compacted area and W shape of micro-catchment achieved the best results compared to the other slopes of 5 and 8% and was better than the normal catchment area and triangle shape. This was attributed to compressing the catchment area with a decreasing soil infiltration rate (Nicholson, 2011) and creating a W shape to encourage the increase of water runoff towards the target area, then increasing water recharge into the soil bottom layer, consequently raising the soil moisture content.

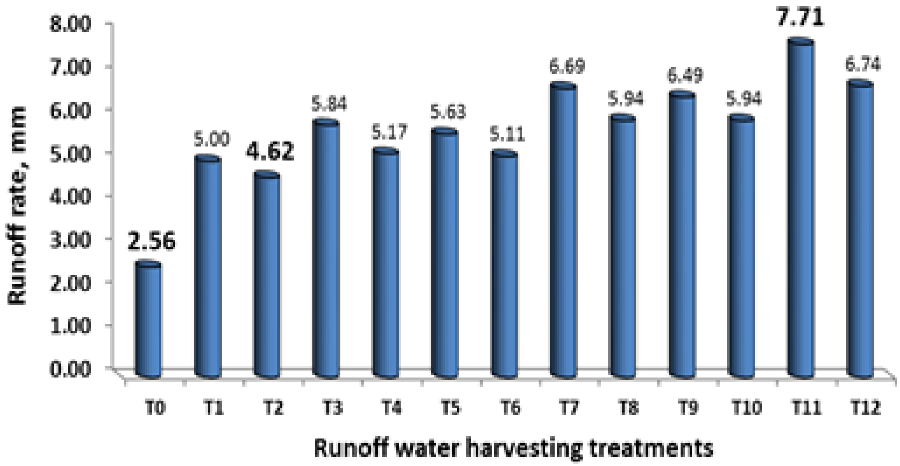

Fig. 3. Effect of different treatments on runoff rate.

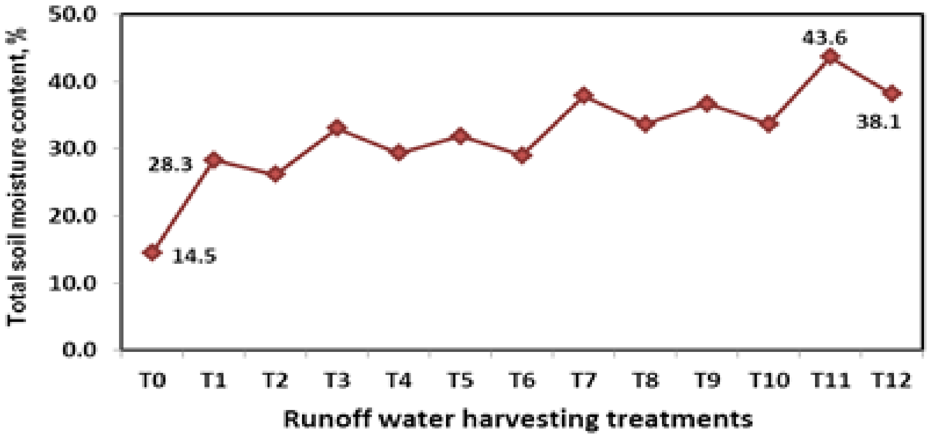

Fig. 4. Effect of different treatments on soil moisture content

3.5. Runoff water harvesting productivity, m³.fed⁻¹

Runoff water harvesting productivity under different treatments was illustrated in Fig. 5. T_{11} recorded the highest value of 32.39 $m^3.fed^{-1}$, while treatments T_0 and T_2 recorded the lowest values of 10.74 and 19.42 $m^3.fed^{-1}$. It was observed that increasing slope and compacting the catchment area increased runoff productivity in order: T_{11}, T_{12}>T_7, T_8 >T_3,T_4 when the catchment slope was 13% > 8% > 5%. The effect of micro-catchment shape was observed under all treatments, so T_{11}>T_{12} in the case of a compacted catchment area and T_9 >T_{10} in the case of a normal catchment area. The lowest values recorded for treatments T_1 and T_2 in order of 21 and 19.42 $m^3.fed^{-1}$, respectively, with the lowest slope of 5% and normal catchment area, in generally a high slope with compacted soil and applied W shape increased runoff-harvesting. This is due to the fact that the longest catchment takes a longer time for runoff flow, while if the main catchment area is divided into small catchment areas, this supports increasing runoff rapidly, (Jourgholami et al., 2017). And compaction of the catchment area reduced the porosity and permeability of the soil, which helped reduce the infiltration rate and increase water flow in the same direction of slope, especially with W shape, which received rainwater runoff in the same direction of slope and gravity, which generated balanced flow, and the vice versa triangle shape, which generated turbulent flow.

3.6. Water harvesting productivity for every tree

When the micro catchment area was 36 m^2 in the field treatments and will be cultivated in the future by trees, everyone feddan comprised 116 trees. Water harvesting for everyone was illustrated in **Figure 6**. The treatment T_{11} recorded the highest value of 279 $L.tree^{-1}$, while T_0 and T_2 recorded the lowest values of 93 and 167 $L.tree^{-1}$, respectively. In general, increasing slope and compacting the micro-catchment area increased runoff productivity in order: T_{11}, T_{12}>T_7, T_8 > T_3, T_4 when the catchment slope was 13% > 8% > 5%. The effect of the micro-catchment shape was observed under all treatments, so T11>T12 in the case of compacted catchment areas and T_9 >T_{10} in the case of normal catchment areas. The lowest values recorded for treatments T_1 and T_2 were 181 and 167 $L.tree^{-1}$ respectively, with the lowest slope of 5% and the normal catchment area. According to the different results, the data emphasized that a high slope with compacted soil and an applied W shape increased runoff productivity and water saving for the target area.

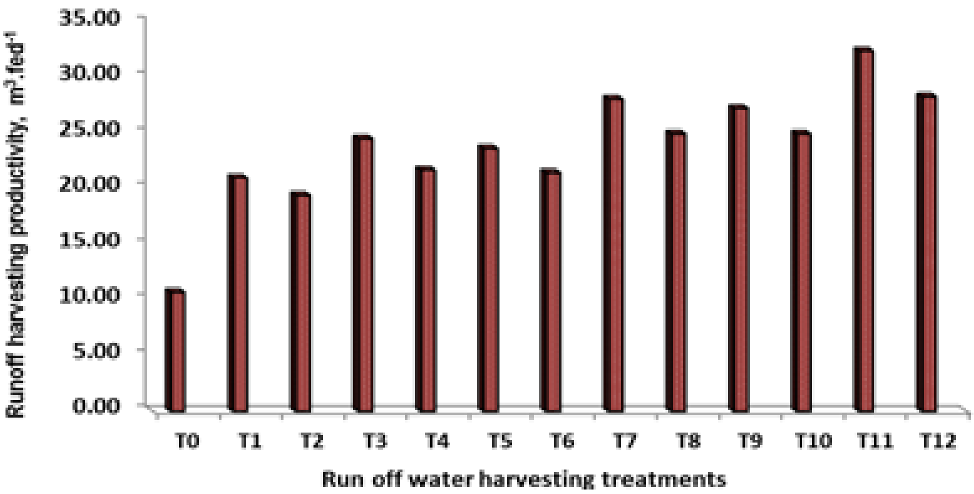

Fig.5. Effect of different treatments on runoff harvesting productivity.

3.7. Water harvesting productivity for every tree

When the micro catchment area was 36 m^2 in the field treatments and will be cultivated in the future by trees, everyone feddan comprised 116 trees. Water harvesting for everyone was illustrated in **Figure 6**. The treatment T_{11} recorded the highest value of 279 $L.tree^{-1}$, while T_0 and T_2 recorded the lowest values of 93 and 167 $L.tree^{-1}$, respectively. In general, increasing slope and compacting the micro-catchment area increased runoff productivity in order: T_{11}, $T_{12}>T_7$, $T_8 >T_3$, T_4 when the catchment slope was 13% > 8% > 5%. The effect of the micro-catchment shape was observed under all treatments, so T11>T12 in the case of compacted catchment areas and $T_9 >T_{10}$ in the case of normal catchment areas. The lowest values recorded for treatments T_1 and T_2 were 181 and 167 $L.tree^{-1}$ respectively, with the lowest slope of 5% and the normal catchment area. According to the different results, the data emphasized that a high slope with compacted soil and an applied W shape increased runoff productivity and water saving for the target area.

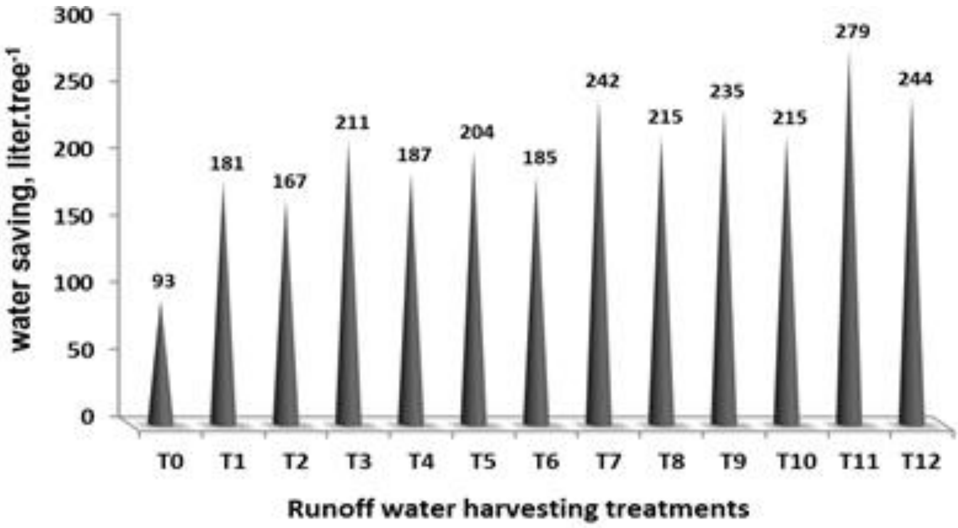

Fig.6. Effect of different treatments on water saving for every tree.

4. Conclusions

Under sloping areas and rain-fed conditions, new methods for runoff water harvesting were developed and applied to convert the sloping areas to a micro catchment and target area and increase runoff flow and water productivity to confront climate change and water scarcity. Results indicated that treatment T_{11}, which comprises a compacted catchment area with W shape of micro-catchment and 13% slope, recorded the highest values of 7.71mm, 32.39$m^3.fed^{-1}$, and 297 $L.tree^{-1}$ for runoff rate, runoff productivity, and water saving for every tree, respectively, while T_0 and T_2 recorded the lowest values with the lowest slop and non-compacted catchment area.

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تطوير طرق حصاد مياه الأمطار تحت ظروف المناطق المنحدرة بوادي الرمل - الساحل الشمالي الغربي - مصر

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الملخص العربي

أساليب وممارسات أرضية جديدة لتجميع مياه الأمطار تحت ظروف المناطق المنحدرة لتحويلها من مناطق تجميع المياه إلى مناطق مستهدفة في ذات الوقت لتعظيم الاستفادة من مياه الجريان السطحي وتخزينها في نفس المنطقة لزراعتها مستقبلاً لرفع كفاءة حصاد المياه والاستغلال الأمثل لوحدة المساحة من خلال تقسيم هذه المناطق إلى عدة مساحات أصغر بالحواجز الترابية.

أجريت التجربة بوادي الرمل بالساحل الشمالي بمحافظة مطروح خلال الموسم الشتوي ٢٠٢٢/٢٠٢٣م وكانت المعاملات كالتالي: ثلاثة ميول (٥ ، ٨ ، ١٣٪) - (منطقة المجمعات العادية والمنضغطة) وشكلين للمجمعات المائية (شكل حرف W، شكل المثلثات المتبادلة). أظهرت النتائج أن المعاملة T_{11} والتي تمثل أعلى ميول ١٣٪ وكبس منطقة التجميع مع استخدام الشكل W كمنطقة تجميع للمياه قد أعطت أفضل النتائج من معدلات الجريان السطحي ونسبة الرطوبة وإنتاجية المياه والتي كانت ٧,٧١مم، ٤٣,٦٪ و ٣٢,٣٩م^{٣}.فدان$^{-١}$ على التوالي. بينما سجلت المعاملة التقليدية T_0 والمعاملة T_2 التى تتضمن أقل الميول ٥٪ مع شكل المثلث لمنطقة التجميع وعدم كبس التربة أقل القيم لمعدل الجريان السطحي وانتاجية المياه على التوالي.