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A New Method for Runoff Water Trapping and Harvesting from the Catchment Area to Increase Water Productivity and Reduce the Sediments in Wadi El Raml-Northwest Coast - Egypt

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ABSTRACT

A new technique method for runoff water trapping and harvesting was applied and experimented to increase runoff water collecting and reducing the soil losses by decreasing the run-off flow time through dividing the long catchment area into several small catchments were separated by earth boundary and installing main access pipe that branched to sub main pipe towards every small catchment. The experiment was applied in the Northwest Coast, Wadi Al-Raml, during the winter seasons of 2021 and 2022. The study was conducted to determine the best parameters that give the best results in terms of surface runoff, water harvested productivity and soil losses estimator during runoff. The following treatments were applied: Three slopes for catchment areas (7%-10%-15%)and two angles of earth boundary (90°-120°) with a comparison to the traditional catchment area. The presented data showed that treatment T_6 which comprised (15 % slop of catchment with soil boundary angle 120°) achieved the optimum values of runoff,11.04 and 9.34 and runoff coefficient, 0.67 and 0.67 During two consecutive seasons. T_0 recorded lowest values of, 3 and 0.20 as annual average of runoff and runoff coefficient respectively. Concerning soil losses traditional treatment T_0 recorded the highest value of 1.20 tan.fed^{-1}, while treatment T_1 which comprised (7 % slop of catchment with soil boundary angle 90°) achieved the lowest and optimum value of 0.59 tan.fed^{-1}. In general, increasing catchment slope and earth boundary angle sustain increasing runoff flow and runoff coefficient

Keywords: Runoff; water harvesting; runoff coefficient; soil losses and productivity.

INTRODUCTION

Drought and water scarcity is one of the most important factors that effect on agricultural activity in arid and semi-arid region, yield was affected by water shortage (Laura *et al.*, 2008). There are two main reasons for the need to focus on rain-fed production: First, the bulk of the world's agricultural production is rain-fed of the 1.5 billion hectares of cropland worldwide and 82 percent is rain-fed (FAO, 2007). Climatic change in the marginal areas of Egypt would induce drought and fluctuation in precipitation (FAO, 2008). Egyptian water resources is limited and it will become water scarcity within a few decades, so rain harvesting is a suitable solution for the North Coast of Mediterranean Sea and the Red Sea (Abdel-Shafy and El-Saharty,2015). Egypt face several fundamental problems: increasing population, a limited arable land and water resources (Zidan and Dawoud,2013). (Zaghloul,2013) showed that the substantial factors contributed to Egypt's food security challenge which are the rapidly growing population, the availability of agricultural land and the restricted water resources. (Abdel-Shafy *et al.*,2010) stated that water harvesting is a supportive element for development, increasing water resources and enhance agriculture live-stock 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. (Mizirai and Tumbo,2010) indicated that water is a primary factor for agriculture development in many arid and semi-arid regions which had much of the annual rainfall occurs, technique of runoff collecting known as runoff harvesting, may be used for food and water production. (Alemu and Kidane,2014) improved in-field water harvesting can increase the time required for crop moisture stress to set in and thus can result in improved the agricultural productivity, water is an important factor for environmental development. (Frone, D. F., and Frone, S., 2015) illustrated that rainwater harvesting has been used since ancient times throughout the world. The earliest known evidence use of this technology in Africa comes from northern Egypt, where tanks ranging from 200-2000m^3 have been used for at least 2000 years. (Ngigi,2003) and (Liniger *et al.*,2006) showed that rainwater-harvesting techniques refer to all technologies where rainwater is collected to make it available for agricultural production or domestic purposes in arid and semi-arid regions, the general design systems involve a catchment area, which collects runoff coming from roofs or ground surfaces and a cultivated area, which receives and concentrates runoff from the catchment area for crop water supply. (Desta, 2004) mentioned that catchment area: the part of the land that contributes some or its entire share of rainwater to the target area outside its boundary. Catchment surfaces can be either natural or treated. However, runoff inducement is a runoff-producing

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area. (Cofie *et al*.,2004) showed that a micro catchment rainwater harvesting system is a method of collecting surface runoff from a small catchment area and storing it in the root zone of an adjacent infiltration area. (Tesfuhuney *et al.*,2013) mentioned that the practical measurements of runoff provided information about which rain events received during the growing season generated varying amounts of runoff according to the rainfall characteristics. (Zhang *et al.*,2013) illustrated that micro catchments have relatively small runoff generation areas (from dozens to hundred sq.m) and are cheap and simple to implement their collection area is usually a small and located nearby 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 divided into basins for storing enough water to allow enough water to be stored for the season. (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.

MATERIALS AND METHODS

1. Experimental site Description:

The field experiment was applied in Wadi El-Raml, Northwest coastal zone, Matrouh, Egypt during two winter seasons of 2021 and 2022. Soil texture was sandy loam. This research aims to determine the effect of using access pipes with divided catchment area into small micro catchment, the slope percent with deviation angle of soil boundary and on rainwater harvested efficiency, sediments and runoff rate. Treatments were: catchment slopes of (7%-10% -15%) and deviation angle of earth boundary (90°-120°). Field experiment design was a split-plot design with three replicates for each treatment. Area of 2700m^2 (90×30m) and was divided into three equal replicates (30×30m) every one comprised six treatments, everyone was (5×30 m) as shown in (Fig 1).

Field experiment treatments:

- T1 : 7 % slop of catchment + 90° soil boundary angle
- T2 : 7 % slop of catchment + 120° soil boundary angle .
- T3 : 10 % slop of catchment + 90° soil boundary angle .
- T4 : 10 % slop of catchment + 120° soil boundary angle .
- T5 : 15 % slop of catchment + 90° soil boundary angle .
- T6 : 15 % slop of catchment + 120° soil boundary angle .
- T0: Traditional treatment.

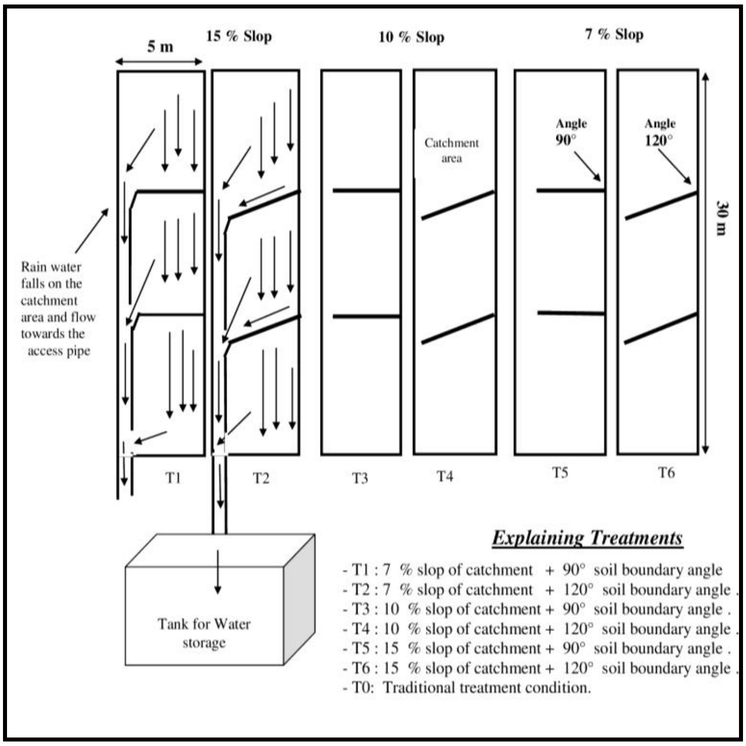

Fig. 1. Experimental field design and treatments

2. Proposed the water harvesting method

The philosophy of the new method of rainwater harvesting is based on trapping surface runoff water, reducing its flow time and the length of the runoff path, and thus reducing water losses by leaching, reducing soil erosion sediments, and then increasing water harvested, this depends on dividing the catchment area into smaller areas in the same direction of slope, and separating them with earthen boundary. A longitudinal pipe is placed on the edge of the catchment area, from which an opening exits at the end of each small catchment area to receive surface runoff water. All runoff water was received in the pipe and flowed to its end toward the storage area, (underground tank) for later use.

3. Rain fall data

Automatically rain fall gauge was fixed in the field study to record rainfall events.

4. Runoff and soil losses measurements

Gerlesh trough with a dimension of 0.5× 0.2 meters was placed at the down-slope edge of a small catchment area for all different treatments to receive surface runoff water and soil losses, (Morgan, 1995) Runoff and soil losses for every effective rainstorm were determined volumetrically and gravimetrically for soil loss after dried it on 105°C. Soil losses rate was defined by dividing sediment weight per unit area. The runoff coefficient was computed as the percentage of Surface runoff rate to total rainfall.

5. Runoff water harvesting productivity, m^3. fed^{-1}

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

$$RWP = \frac{Rv \times 4200}{1000}$$

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

RESULTS AND DISCUSSION

1. Rainfall Data

Rainfall Data are indicated in Figure 2. Rain event during seasons 2021/ 2022 and 2022/2023 occurred from October to April, total events were 165.8 and 138.6mm in the first and second season respectively.

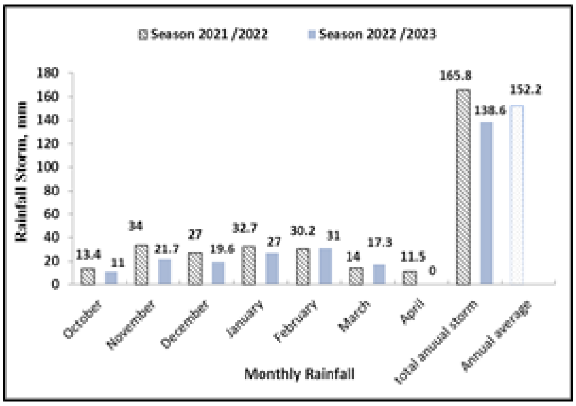

Fig. 2. Rainfall data during two winter seasons

The annual average was 152.2mm. Monthly rain rates were variable and different, the first storm occurred in October and reached 13.4 and 11mm for the first and second seasons respectively, It was observed that rainfall in April was Zero in the second season. November and February recorded the highest event storm which was 34 and 30.2 respectively in the first season and 21.7, 31mm in the second one. The lowest storm occurred in October and April during each season, the rainiest month was April in the second season.

2. Effect of different treatments on runoff and runoff coefficient

Data in Table 1 illustrated the effect of treatments on runoff and runoff coefficient. Generally, increasing rainfall amount, catchment slope and earth boundary angle increased runoff and runoff coefficient. Technique T_6 recorded the highest value of the annual average of total runoff, 10.19mm when the runoff coefficient was,0.067, while T_0 and T_1 recorded the lowest values of 3.0 and 6.14mm respectively. Runoff coefficient followed the same pattern. Data illustrated that $T_2 > T_1$, $T_4 > T_3$ and $T_6 > T_5$ when the earth boundary angle was 120° >90°, annual average for the maximum and minimum values were recorded in the case of T_6 and T_0 respectively which reached 0.067 and 0.020. Data explained that the minimum values of runoff occurred when catchment length increased. This is due to that 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). Traditional treatment T_0 which is the longest catchment and not divided into mini catchments generated the lowest average values of runoff and runoff coefficient.

Table 1. Effect of different treatments Runoff and on runoff coefficient.

Treatments	Season 2021/2022		Season 2022/2023		annual average	
	Total runoff,(mm)	Runoff coefficient	Total runoff,(mm)	Runoff coefficient	Total runoff,(mm)	Runoff coefficient
T1	6.78	0.041	5.50	0.040	6.14	0.040
T2	6.85	0.041	6.64	0.048	6.75	0.045
T3	7.98	0.048	6.38	0.046	7.18	0.047
T4	9.80	0.059	7.39	0.053	8.59	0.056
T5	8.94	0.054	7.55	0.055	8.25	0.054
T6	11.04	0.067	9.34	0.067	10.19	0.067
T_0	3.33	0.020	2.66	0.019	3.00	0.020

3. Effect of different treatments on soil losses

The differences between the traditional method and the others on soil losses, $tan.fed^{-1}$ were shown in Table 2 , T_1 which is considered the lower slope recorded the lowest values of annual average soil losses of 0.59 $tan.fed^{-1}$, compared to the other treatments which recorded the highest values of soil losses of 1.20, 0.99 and 0.86 $tan.fed^{-1}$ with T_0 , T_6 and T_4 respectively .

Table 2. Effect of different treatments on soil losses($tan.fed^{-1}$).

Treatments	Season 2021/2022								Season 2022/2023							Annual average of Soil losses, $tan.fed^{-1}$
	Rainfall storm							Total Soil losses, $tan.fed^{-1}$	Rainfall storm						Total Soil losses, $tan.fed^{-1}$	
	13.4	34	27	32.7	30.2	14	11.5		11	21.7	19.6	27	31	17.3		
T1	0.058	0.125	0.105	0.123	0.111	0.049	0.043	0.61	0.047	0.092	0.085	0.122	0.138	0.075	0.56	0.59
T2	0.066	0.143	0.120	0.141	0.127	0.056	0.049	0.70	0.054	0.106	0.098	0.140	0.159	0.087	0.64	0.67
T3	0.068	0.155	0.130	0.153	0.140	0.061	0.054	0.76	0.055	0.107	0.102	0.142	0.163	0.088	0.66	0.71
T4	0.081	0.185	0.155	0.182	0.167	0.069	0.064	0.90	0.067	0.134	0.126	0.178	0.204	0.109	0.82	0.86
T5	0.079	0.176	0.143	0.168	0.151	0.067	0.059	0.84	0.063	0.123	0.113	0.164	0.188	0.101	0.75	0.80
T6	0.091	0.213	0.173	0.207	0.183	0.081	0.074	1.02	0.083	0.155	0.142	0.209	0.237	0.130	0.96	0.99
T0	0.112	0.269	0.219	0.265	0.245	0.114	0.093	1.32	0.094	0.179	0.167	0.233	0.270	0.147	1.09	1.20

In this respects, Increasing slopes of catchment and flow path are induced increasing soil losses, (El Kateb *et al.*,2013) and (Zhang *et al.*,2018) in the order:T_6,T_5>T_4,T_3>T_2,T_1 with slopes of 15, 10 and

7%Respectively.The effect of the earth boundary angle was less than the effect of the catchment slope. The role of rainfall storm was observed when the highest storm 32.7 and 31mm induced the maximum values of soil losses for all treatments. All results are due to that increasing the catchment slope increases runoff flow rapidly from up to down of catchment which generates more amount of soil losses.

4. Runoff water harvesting productivity, $m^3.fed^{-1}$

The effect of different runoff water harvesting treatments on an annual average of runoff productivity was shown in Figure 3.

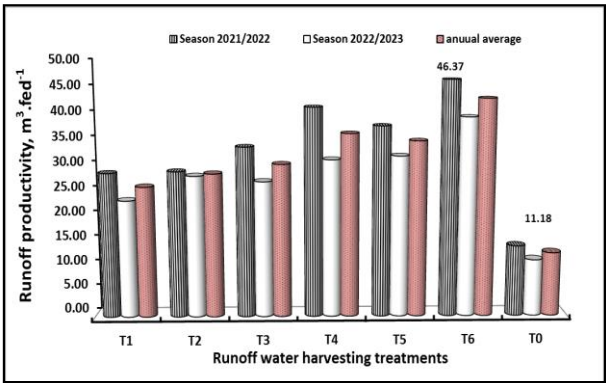

Fig. 3. Effect of different treatments on runoff water productivity

Runoff water harvesting method (T_6) generated the highest value of 46.37 $m^3.fed^{-1}$, while traditional treatment T_0 gave the lowest values of 11.18 $m^3.fed^{-1}$. It was observed that increasing slope increased runoff productivity in order: T_6 , T_5>T_4 ,T_3 >T_2,T_1 when catchment slop was 15% > 10% > 7% respectively, and the effect of earth boundary angle took the same trend so, $T_6 > T_5$, $T_4 > T_3$ and T_2>T_1 when earth boundary angle was 120° >90°.This is due to that the longest catchment takes a longer time for runoff flow while if the main catchment area is divided into small catchment area this support increasing runoff rapidly, (Jourgholami *et al.,* 2017). The idea of receiving more runoff water from every mini catchment directly to access pipes increased runoff productivity with a less runoff losses.

CONCLUSION

Under rain-fed conditions, new methods for runoff rainfall trapping and harvesting were applied to increase runoff flow and reduce soil losses. Results showed that treatment T_6 which comprises a 15% slope of catchment and earth boundary angle of 120° achieved the highest value of,10.19mm, 0.67 and 42.80$m^3.fed^{-1}$ as annual average for runoff, runoff coefficient and runoff productivity respectively, while traditional method T_0 recorded the lowest values. Soil losses reached the maximum and minimum values of 1.20 and 0.59tan.fed^{-1} with treatments of T_0 and T_1 respectively. In general, dividing the catchment area into several small catchments and increasing the slope and orientation of runoff flow through access pipes that sustain and increase runoff flow rapidly from up to the down of the catchment area, so the research support more studies and practices which sustain increasing runoff water harvesting and water saving to confront water scarcity crisis in the future.

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طريقة جديدة لمحاصرة وحصاد مياه الجريان السطحي من مناطق التجميع لزيادة إنتاجية المياه وتقليل الرواسب بوادي الرمل - الساحل الشمالي الغربي - مصر

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الملخص

طريقة جديدة لمحاصرة وحصاد مياه الجريان السطحي للأمطار من مناطق التجميع وتقليل الرواسب المنجرفة منها من خلال تقليل زمن الجريان والمسافة التي يقطعها بواسطة تقسيم منطقة التجميع الى عدة احواض صغيرة مع تركب ماسورة بنفس اتجاه ميول منطقة التجميع يتفرع منها مواسير جانبيه باتجاه كل حوض لالتقاط المياه منها الى داخل الماسورة الرئيسية وتوجيها الى خزانات ارضية لاستغلالها بعد ذلك. تم تطبيق التجربة بالساحل الشمالي الغربي بوادي الرمل بمحافظة شمال سيناء خلال الموسمين الشتويين 2021 و 2022 لتحديد افضل المعاملات التي تعطى افضل النتائج من معدلات جريان سطحي وانتاجية المياه المحصودة ومقدار فاقد التربة , وكانت المعاملات كالتالي: ثلاث ميول لمناطق تجميع (7% - 10% - 15%) - زاويتين ميول للحاجز الترابي (البتن) (90 - 120 درجة) مع مقارنة ذلك بمنطقة التجميع التقليدية. أوضحت النتائج ان المعاملة T_6 والتي تمثل ميول منطقة التجميع 15% مع زاوية ميول البتن 120 درجة قد اعطت أعلى قيم للجريان السطحي 11.04 و 9.34 ومعامل الجريان السطحي 0.67 و 0.67 للموسم الاول والثاني على التوالي ,.اعطت الطريقة التقليدية T_0 اقل متوسط سنوي للجريان السطحي ومعامل الجريان بقيمة 3 و 0.20 على التوالي .وبخصوص فواقد التربة فإن المعاملة التقليدية اعطت اعلى القيم بمقدار 1.20 طن للفدان بينما اعطت المعاملة T_1 اقل المعدلات بمقدار 0.59 طن/فدان , وبصفة عامة فإن زيادة انحدار منطقة التجميع وزاوية ميول البتن يزيد من معدلات الجريان السطحي للمياه المحصودة لذلك كانت القيم للمعاملات