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DEVELOPMENT OF A NEGARIM MICRO-CATCHMENT SYSTEM FOR CITRUS PRODUCTION

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ABSTRACT

A Negarim Micro-catchment System can be considered as a rudimentary form of irrigation and it is a directly productive form of soil and water conservation which focused on harvesting and conserving rainwater for improved crop productivity. The system was designed and constructed. The system consists of the catchment area, cultivated area, runoff plot, runoff gutter and collection tank. Results of the analysis revealed that on average, an annual rainfall of 1,233.6mm or higher can be expected at 50% probability of occurrence and at average frequency of occurrence of 1,233.61mm or higher can be expected a 50% probability of occurrence of 2½years interval. The results also showed that the mean runoff coefficient for the catchment throughout the period of observations is 0.48, the average value of crop water requirement is 3.63mm/month, the chemical analysis results also showed that the salinity, infiltration rate, toxicity and fertility level of the soil in the study area are satisfactory and suitable for citrus production and finally, the average catchment-cultivated area ratio (C:CA) is 1.0478. However, if the available rain can be concentrated on a small area, through water harvesting system, both yields and reliability of production can be significantly improved.

Keywords: Micro-catchment, Runoff Gutter, Infiltration Pit, Catchment Area, Cultivated Area, Runoff Plot.

INTRODUCTION

The term micro-catchments were introduced by Israeli scientists who studied catchments of about one tenth of a hectare during the 1970's. The basic micro-catchment consists of two parts, the catchment area and infiltration basin. Rainfall runoff is collected from a small catchment area that has been cleared or otherwise lacking vegetation. The concentrated runoff is stored on or in the soil profile of an adjacent infiltration basin for growing crops (Hilary and Gary, 1995).

Micro-catchment systems are a common technique used in agriculture to collect surface runoff, increase water infiltration and prevent soil erosion. Their principle is comparably simple. Small pools are surrounded by stone walls and/or soil ridges on all sides to collect the rainwater and surface runoff. This allows storing rainwater and using it for small-scale tree and bush planting, enabling increased growth of plants if there is a moisture deficit. The basins may vary strongly in size (ranging between 10 and 100m^2) depending on the planted crop. Sometimes, basins are also constructed directly around the plant (Ali *et al*., 2009).

Different design types are possible, including half-moon, v-shaped, diamond-shaped, trapezoidal, as well as contour bund basins. V-shaped micro catchments are also called "Negarims" (Malesu, 2007). Negarim is derived from the Hebrew word "Negev" meaning runoff. It was popularized in Israel Negev desert and appropriate in arid or semi-arid conditions with as low as 100-150 mm rainfall per annum. A Negarim micro-catchment system is one of the water harvesting schemes for tree production and is diamond – shaped basins surrounded by small earth bunds with an infiltration pit in the lowest corner of each. Runoff is collected from within the basin and stored in the infiltration pit. Besides harvesting water for the trees, it simultaneously conserves soil. Negarim micro catchment is neat and precise, and relatively easy to construct.

Water harvesting can be considered as a rudimentary form of irrigation. The difference is that with water harvesting the farmer (or more usually, the agro-pastoralist) has no control over timing. Runoff can only be harvested when it rains (FAO, 1991).Water harvesting in its broadest sense can be defined as the "collection of runoff for its productive use". Productive use include; provision of domestic and stock water, concentration of runoff for crops, fodder and tree production and less frequently supply for fish and duck ponds. Collecting, capture or diverting rainwater for various productive usages is wide spread. Especially for agricultural purposes and soil/water conservation, the use of micro catchment structures has been adopted in numerous projects and is considered as “state of the art” approaches. In addition, several international organisations and institutions conduct substantial research on methods to augment water availability for food production (ADB, 2008).

The water harvesting process is distinguished from irrigation by three key features: first, the’ catchments’ area is contiguous with the benefiting target area and it is relatively small; second, the application to the target area is essentially uncontrolled- the objective is simply to capture as much water as possible and store it within the reach of the plant(s), in the soil profile of a cultivated area or into some time of reservoir; third, water harvesting can be used to concentrate rainfall for purposes other than crop production (Theib *et al*., 1999).

Water harvesting technology is especially relevant to the semi-arid and arid areas where the problems of environmental degradation, drought and population pressures are most evident. It is an important component of the package of remedies for these problem zones, and there is no doubt that implementation of water harvesting techniques will expand (FAO, 1991). Therefore, water harvesting systems are directly productive form of soil and water conservation in which both yields and reliability of production can be significantl improved.

It is in the light of the above that this study is aim at design and construction of a Negarim Micro catchment system for Citrus fruit plantation and to evaluate the runoff coefficient for the study area from the field measurement of runoff and rainfall.

MATERIALS AND METHODS

Location of the Study Area

The study area is located within Agricultural and Bio-Environmental Engineering Demonstration Farm Site, Kwara State Polytechnic, Ilorin, Kwara State, Nigeria. It lies around the latitude of $08^0$36' North and longitude $04^0$29' East. It is situated on the altitude of approximately 344.13m above sea level and the total area of the field used is (24.6m x 11.9m) 292.74m^2.

Selection of Materials for Construction

The main materials generally use for the construction of water harvesting systems are soils and stones. The ability of a soil to form resilient earth bunds is very important. Generally, the soils which should particularly be avoided are those which crack on drying, namely those which contain a high proportion of montmorillonite clay (especially vertisols or black cotton soils), and those which form erodible bunds, namely very sandy soils, or soils with very poor structure. The availability of stones for stone pitching within the local area has to be considered in the selection of materials for water harvesting system and labour requirements are very sensitive to availability of stone (FAO, 1991).

Physical Design Considerations

Precipitation

Water harvesting is of significant interest in arid and semi-arid regions where crop growth is restricted by infrequent or limited precipitation. These areas have very unpredictable precipitation patterns and quantities. The frequency of rain and probability of certain intensities and amounts is more important than the annual quantity. It is usually desirable to look at monthly or growing season precipitation quantities as opposed to annual precipitation amounts. It is easier to design the necessary size of the water harvesting structures with information on rainfall during the growing season rather than annual quantities. When possible, analysing a ten year minimum climate record is recommended.

Soils

The soils of micro catchment water harvesting site must function as a water storage facility, medium for plant growth, and a water collection surface. These soil conditions must all be met in a single area. Because of this, the soil depth and texture are important physical elements necessary to understand and to design successful micro catchment systems. Besides possessing good water holding and infiltration properties, the soil texture must also be able to generate runoff in the catchment area. Another important quality of soil texture to consider is the erosion potential. Highly erodible soils which are self-mulching or well-structured do not make durable crusts and should be avoided. Micro-catchments on clay soils with medium to fine texture are the best at generating sufficient runoff and are not susceptible to erosion.

Slope

In micro catchment systems, the slope is an important design factor for the catchment area which affects the quantity and quality of water generated. Slopes that are too steep may erode and produce high amounts of sediment in the runoff water. On very flat slopes, water is lost by retention in small depressions. The retained water either infiltrates into the soil or is evaporated into the atmosphere and lost. The most efficient water harvesting systems are usually on slopes of 3 to 5 percent.

Technical Design Considerations

Runoff/Run on Area Ratios

For micro catchments, the ratio of the runoff area to the infiltration basin area is an important technical design consideration. Major factors for consideration in determining the proper catchment/cultivated area ratio are: the climate (precipitation quantity and timing); geomorphology (slope and soil texture); crop type (water requirements); and the runoff efficiency of the collecting area. Generally, the ratio can vary between 1:1 to 20:1 depending upon the site conditions, precipitation characteristics, and crop water needs.

Runoff Efficiency

For designing micro catchment structures, an important component is the catchment runoff efficiency. The runoff efficiency is defined as the percentage of total rainfall which is harvested as runoff. The efficiency of the system, the amount of runoff collected in relation to precipitation, depends on storm duration and intensity, and antecedent soil water. Typical runoff efficiencies range from 30 to 50 percent of average monthly precipitation.

Agronomic Features

The application of mulch and organic matter is a notable feature of the technical design considerations for micro catchment water harvesting systems. The addition of mulch and organic matter in the infiltration basin area can significantly improve soil structure, and increase fertility and infiltration, while decreasing soil water evaporation.

Plant Species

Selection of the proper plant species is one of the most important technical design considerations for micro catchments. Because water harvesting systems increase the amount of water availability to crops, certain types of plants can survive drought periods and produce greater yields. With these systems, plant species that are able to endure periods of intermittently wet or dry soil will benefit. Plants utilized in water harvesting systems should possess deep roots and have water requirements which match local rainfall patterns.

MATERIAL AND METHODS

Negarim Micro-catchment System Design

Evaluation of Crop Water Requirements

Thirty years of climatic data (evaporation rates) were obtained (1986-2015), from Lower Niger River Basin Development Authority (LNRBDA), Kwara State, Nigeria. The daily evaporation values obtained were summed and averaged to obtain the mean daily and monthly evaporation rates. The monthly evaporation rates (E_{rate}) were multiplied by pan coefficient (K_{pan}) to give reference evapotranspiration. Thus:

$$ET_0 = E_{rate} x\, K_{pan} \quad (1)$$

Source: FAO (1986)

For Class A evaporation Pan, K_{pan} varies between 0.35 and 0.85, with an average value of 0.70. The average K_{pan} was multiplied by mean monthly evaporation rates to determine the mean monthly reference evapotranspiration (ET_o). This was finally multiplied by the crop coefficient (Citrus = 0.50 at 20% Canopy) to get the crop water requirement (ET_c).

Soil Sampling and Analysis

Nine soil samples were randomly collected at the depths of 0-20cm, 20-40cm and 40-60cm, respectively, using soil auger and were taken to soil laboratory for both physical and technical analysis. Textural text was performed using sieves of various pores diameters and sizes from 0.0 – 0.2, in order to evaluate the suitability of the in-situ soil for this Negarim micro catchment system. Among the parameters evaluated are; Electrical conductivity (EC_w), Cations and Anions (Ca^{++}, Mg^{++}, Na^+, CO_3, HCO_3, Cl^-, SO_4^{--}), Nutrients (Nitrate – Nitrogen NO_3 – N, Ammonium – Nitrogen NH_4^- - N, Phosphate – Phosphorus PO_4 – P, Potassium K^+), Acidity/Basicity (P^H), Water saturation percentage (%) and Exchangeable sodium percentage (%).

Design Rainfall and Probability Analysis

The design rainfall is usually assigned to a certain probability of occurrence. The design rainfall was determined by means of a statistical probability analysis. Thirty years of annual rainfall totals (from LNRBDA; 1986 – 2015) were used for this analysis. The probability of occurrence P (%) for each of the ranked observations was calculated as thus:

$$P\ (\%) = \frac{(M-0.375)}{(N+0.25)}\ x100 \ .... (2)$$

Source: FAO (1991)

Where,
P = probability in (%) of the observation of rank (m)
M = the rank of the observation and
N = total number of observations used.
0.375 and 0.25 are the constants of the equation

Then, ranked observations were plotted against the corresponding probabilities, using normal probability paper and the curve generated was straight line in nature. Finally, the return period (T) was then derived, since the exceedance probability P (%) was known;

$$T = \frac{100\ (\text{years})}{P} \qquad .... (3)$$

Design Model for Catchment: Cultivated Area Ratio

For an appropriate design of water harvesting (WH) system it is required to determine the ratio between catchment (C) and cultivated area (CA). This can be computed using the following Equation:

$$\frac{\text{Catchment Area}}{\textit{Cultivated Area}} = \frac{\text{Crop Water Requirement} - \text{Design Rainfall}}{\text{Design Rainfall x Runoff Coefficient x Efficiency Factor}} \ .. (4)$$

Source: FAO (1991)

The runoff coefficient value ranges between 0.1 and 0.5 with average value of 0.3 and efficiency factor ranges between 0.5 and 0.75 with average value of 0.625 were used to determine C: CA by substituting the known value of crop water requirement and design rainfall in Equation 4.

Field Layout and Construction Procedure

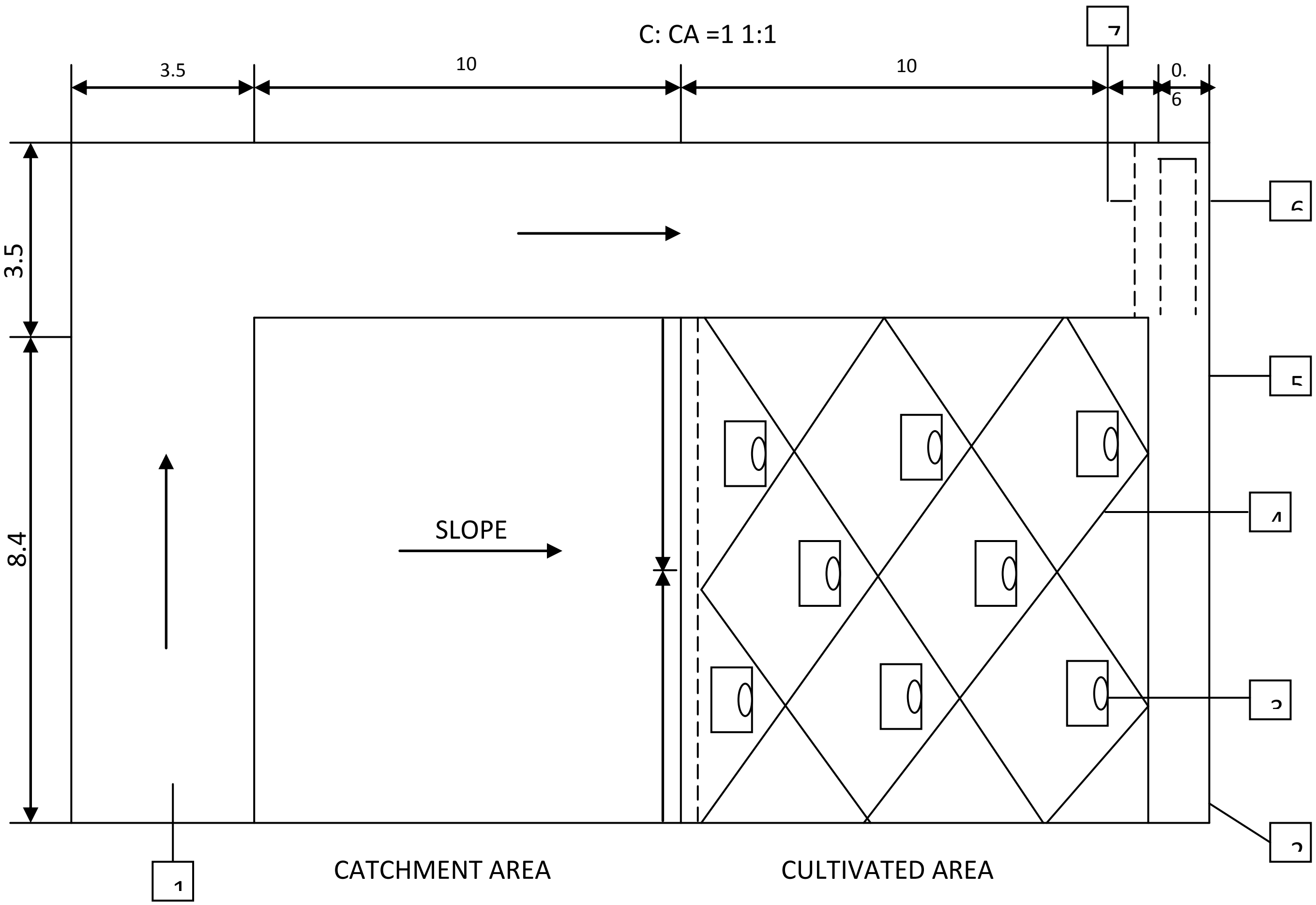
The first step is the establishment of the contour line and the ground slope which was done using a line level. By means of a measuring tape, the tips of the bunds were marked along the ‘straightened contour’. The first line was open – ended. The distance between the tips (a – b) is 4.2cm which depends on the selected catchment size of 3m x 3m.
A piece of string as long as the side length of the catchment (4.2m for a 3m x 3m) was held at one tip (a) and a second string of the same length at the other tip (b). The two exactly met at the apex (c). The apex was marked with a peg and the catchment sides (a – c) and (b – c) marked on the ground alongside the strings with a hoe. This procedure was repeated until all bund alignments in the first row were determined.
The next row of micro catchments was then staked out. The apexes of the bunds of the upper row were the tips for the second row and the corresponding were found. When the second row of micro catchments has been marked, the procedure was repeated for the third row, etc. The final result was a block of diamond – shaped micro catchments, with a first row which was open at the up slope end. The size of the infiltration pits were staked out and the pits were excavated, leaving a small step towards the back on which the citrus seedlings were planted. The bunds were constructed in two layers. The excavated materials from the pits were used to form the bunds and the bunds were compacted during construction, using a barrel filled with sand. The diversion ditch

was made above the block of micro catchments to avoid the risk of damage by runoff from up slope of the block. The overall field layout of a Negarim micro-catchment system is shown in Figure 1.

Estimation of Runoff Coefficient (K) for the Study Area

An analysis of the rainfall–runoff relationship and subsequently an assessment of relevant runoff coefficient (k) are best done based on actual, simultaneous measurements of both rainfall and runoff in the study area. The runoff coefficient is defined as runoff divided by the corresponding rainfall both expressed as depth over catchment area (mm). Rainfall and Runoff readings taken after every rainfall event were averaged and used to compute runoff coefficient, by dividing the runoff against the corresponding rainfall.

$$Runoff\ Coefficient\ (K) = \frac{\text{Runoff}}{\text{Rainfall}} \quad (5)$$



7	Drop Structure
6	Stone Pitching
5	Runoff Gutter
4	Micro-catchment Unit
3	Infiltration Pit
2	Collection Tank
1	Runoff Plot

Figure 1: Overall field layout of a Negarim Micro-Catchment System

RESULTS AND DISCUSSION

Results of Analysis

The results of crop water requirement, probability analysis, and runoff coefficient and soil analysis were presented in Table 1, 2, 3 and 4, respectively.

Table 1: Crop Water Requirement (1986 – 2015)

S/No	Year	erence Evapotranspiration (ETo)	Water Requirement (ETc)
1	1986	8.23	4.12
2	1987	8.66	4.33
3	1988	8.31	4.16
4	1989	8.18	4.09
5	1990	8.01	4.01
6	1991	8.00	4.00
7	1992	8.67	4.34
8	1993	8.12	4.06
9	1994	6.29	3.15
10	1995	4.45	2.23
11	1996	1.47	0.74
12	1997	4.37	2.19
13	1998	4.53	2.27
14	1999	5.40	2.70
15	2000	4.97	2.49
16	2001	6.49	3.25
17	2002	7.33	3.62
18	2003	5.66	2.83
19	2004	3.31	1.68
20	2005	0.69	0.35
21	2006	5.93	2.97
22	2007	12.17	6.09
23	2008	4.53	2.27
24	2009	2.53	1.27
25	2010	6.52	3.26
26	2011	2.28	1.14
27	2012	1.47	0.74
28	2013	9.35	4.68
29	2014	5.81	2.91
30	2015	9.00	4.50
	Total		**90.44**
	Mean		**3.02**

Table 2: Probability Analysis

S/No	'ear	nfall (mm)	anking (M)	bility (P) (%)	n Period (T) (Year)
1	986	1272.5	1750.4	57.85	1.73
2	987	1323.9	1515.9	50.1	2.00
3	988	1278.2	1503.2	49.68	2.01
4	989	1233.4	1495.0	49.41	2.02
5	990	1035.1	1474.3	48.72	2.05
6	991	1326.7	1454.9	48.08	2.08
7	992	838.6	1450.5	47.94	2.09
8	993	1495	1396.1	46.14	2.17
9	994	1750.4	1393.9	46.07	2.17
10	995	1396.1	1353.2	44.73	2.24
11	996	990.2	1326.7	43.85	2.28
12	997	1503.2	1323.9	43.75	2.29
13	998	980.7	1294.9	42.79	2.34
14	999	1294.9	1278.2	42.24	2.37
15	000	892.1	1272.5	42.05	2.38
16	001	744.2	1272.0	42.04	2.38
17	002	1068.8	1244.0	41.11	2.43
18	003	1215.9	1233.4	40.76	2.45
19	004	1272	1222.6	40.40	2.48
20	005	1092	1215.9	40.18	2.49
21	006	1353.2	1168.0	38.60	2.59
22	007	1474.3	1092.0	36.09	2.77
23	008	1515.9	1068.8	35.32	2.83
24	009	1393.9	1046.6	34.59	2.89
25	010	1046.6	1035.1	34.21	2.92
26	011	1450.5	990.2	32.72	3.06
27	012	1454.9	980.7	32.41	3.09
28	013	1222.6	892.1	29.48	3.39
29	014	1244	838.6	27.71	3.61
30	015	1168	744.2	24.59	4.07
	otal			**1233.61**	**75.67**
	[ean			**41.12**	**2.52**

Table 3: Runoff Coefficient (K) from Field Measurements

	f (mm)	all (mm)	f Coefficient (K)
16			
16			
16			
16			
16			
016			
016			
016			
16			
16			
16			
16			
016			
016			
016			
016			
016			
16			
16			
16			
016			
016			
016			
016			
016			

Table 4: Soil Chemical Analysis Results

ACCT. /LAB. NO
of Horizon or Soil layer (cm)
Water (suspension 1:2)
1m kcl (suspension 1:2)
Extract 1:2.5)
ngeable Cation Ca++(Cmol/kg of soil)
ngeable Cation Mg++ (Cmol/kg of soil)
ngeable Cation Na+ (Cmol/kg of soil)
ngeable Cation K+ (Cmol/kg of soil)
ı Exchange Capacity (CEC) (Cmol/kg of soil)
Saturation (%)
ngeable Acidity (Cmol/kg of soil)
ngeable Sodium Percentage (ESP) (%)
Ammonium Nitrogen (%) (Kieldahi)
ıble Phosphorus (Bray 1) ppm
Saturation Percentage (%)

DISCUSSION

The average value of ET_c across the period of record (1986 – 2015) is 3.02mm/month, using the climatic data obtained from meteorological department, Lower Niger River Basin Development Authority (LNRBDA). This has been used to compute the catchment – cultivated area ratio (C: CA). The computed catchment – cultivated area ratio is 1.05. This shows that the catchment – cultivated area ratio is approximately 1:1; this indicated that both catchment area and cultivated area are equal in dimensions. On average, an annual rainfall of 1,233.61mm or higher can be expected at 50% probability of occurrence in 2½ years interval.. The mean runoff coefficient (K) for the study area cross the period of observations is 0.48; this indicates that enough runoff will be available in the cultivated area for plant growth.

Soil physical and chemical analyses were carried out to evaluate the characteristic properties of the in-situ soil. Physical analysis result shows that the soil in the study area is sandy loam, using textural classification triangle chart by United State Department of Agriculture (USDA). Chemical analysis result showed that the salinity infiltration rate, toxicity and fertility level of the soil in the study area are found under 'none' category, using the 'Guidelines for the interpretations of water quality for agricultures by FAO (1994). This implies that the level is satisfactory, having little or no negative effect on the yield of the crop.

CONCLUSIONS

The following conclusions were drawn from the results of this study:

i. Crop water requirement of citrus is 3.02mm/month.
ii. Soil in the study area is sandy loam.
iii. Salinity, infiltration rate, toxicity and fertility level of the soil are found suitable for plant production.
iv. The average an annual rainfall of 1,233.61mm or higher can be expected a 50% probability of occurrence and at average frequency of occurrence of 2½ years interval.
v. The average C: CA ratio is 1.05, i.e. C: CA = 1:1.
vi. The mean runoff coefficient for the catchment area throughout the period of observation is 0.48.

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