Adoption of Rainwater Harvesting Technologies by Farmers in Tanzania with Particular Reference to the Western Pare Lowlands.

Senkondo, E.M.M[1*]., E.A. Lazaro[1] and G. J. Kajiru[2]

[1] Department of Agricultural Economics and Agribusiness, Sokoine University of Agriculture, Tanzania

[2]Ukiriguru Research and Training Institute, Ministry of Agriculture and Co-operatives, Tanzania

Abstract

Adoption of technology is an important factor in economic development. Successful introduction of technologies in the developing countries requires an understanding of the priorities and concerns of the smallholder farmers at the grassroots. This paper presents experiences of adoption studies in the Western Pare Lowlands, identifying the factors affecting adoption, constraints to adoption and methodological problems in studying adoption of RWH technologies. A survey approach was the main method used to collect the data from a sample of 86 farmers. The data collected were analysed using descriptive statistics and estimation of empirical model to determine the factors affecting adoption of RWH technologies. The empirical model used was logit regression. Important factors affecting the adoption of RWH were identified as number of plots owned by farmers and the sex of the head of household. Constraints in the adoption of RWH technologies were noted including constraints facing those who are already using the RWH technologies. Problems facing the users include difficulties with water distribution. Two important recommendations are made: First because adoption of technologies by farmers takes time, there is a need for collecting a series of data (separated in time) about adoption rather than depending on single season static data. The models used in evaluating adoption should also consider the time element. Secondly, since the main constraints to adoption is lack of technical knowledge, it is recommended that training of extension workers in RWH techniques and including RWH in the district extension package will reduce the problem of availability of technical knowledge to farmers.

Key words: Adoption, probit, logit regression, technology characteristics, rainwater harvesting

Introduction

Adoption of technology is an important factor for economic development especially in developing countries. Consequently many adoption studies have been undertaken to single out the most important factors that determine the diffusion of innovations. Since the earlier work of Rodgers (1962), efforts to explain determinants of adoption have been expanded (for example Feder *et al.*, 1985 and Nkonya *et al.*, 1997).

Feder *et al.* (1985) define adoption as the degree to which a new technology is used in long-run equilibrium when farmers have complete information about the technology and its potential. On the other hand, aggregate adoption is defined as the process of diffusion of a new technology within a given geographical region. Adoption at the farm level is related to

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[*] **Corresponding author**

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Conclusion

Micro-catchment RWH for maize production would significantly improve the productivity of labour and other inputs in an area of very low rainfall (less than 300 mm per season) or *Vuli* seasons. However, the benefits of the system can only be realised if the rainfall distribution is such that a high proportion is obtained during the beginning of the season. At the same time, the system does not give significant benefits during *Masika* seasons. In general, micro-catchments for maize production can be justified and would be accepted only in areas where there is no scarcity of good land for cultivation, to allow for the requirement to have a catchment area adjacent to the crop basin.

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Combined effect

At Kisangara during *Masika*, overall highest yield was observed in treatment T3 (4:1 CBAR, Flat Cultivation) with a long-term mean grain yield of 2,779 kgha^{-1} (Table 5). There was a significant difference (P = 0.05) between the treatments during *Vuli* in Kisangara. The highest grain yield was obtained in treatment T5 (2:1, Staggered Ridges). In Morogoro there was no significant difference of the treatments.

Discussion

This study has shown that the yield increase benefits obtained from micro-catchment RWH are low during *Masika* season on both sites. The main explanation is that the crop water requirement is adequately met during this season (Figure 4). This explains the minimal effect obtained from addition of water. This is also made clear by estimation of CBAR illustrated in equation 7. During *Vuli*, the benefits from RWH were large indicating that soil-water available to plants is limiting as illustrated in equation 6. However, the low overall yields compared to *Masika* indicate that the CBAR used in this study were too low. The difference between *Vuli* and *Masika* in relation to the performance would be as expected. Similar trends have been observed in experiments in Kenya (Critchley, 1989; Kilewe and Ulsaker, 1984).

The total failure of the crop to yield grain in Morogoro during *Vuli* requires some explanation. An analysis of the long-term rainfall patterns of both Kisangara and Morogoro may provide the explanation (Mahoo *et al.*, 1999). In Morogoro the *Vuli* season starts very late, as indicated by monthly rainfall amounts. Rainfall expected 70% of the time during the months of October, November, December and January, is 10 mm, 37 mm, 59 mm and 48 mm, respectively. In Kisangara, the trend is 8 mm, 78 mm, 52 mm and 18 mm. Therefore, rainfall during the first two months of the season
Morogoro was only 50% of what was obtaine
in Kisangara. This means that there was le
rainwater to harvest in Morogoro at the begi
ning of the *Vuli* season, which reduced th
benefits of RWH. This is an important facto
in determining the potential of RWH as di
cussed by other researchers such as Frais
(1990) and Perrier (1988), as quoted by Owe
et al. (1999). These findings show the impo
tance of using shorter durations (such
monthly or even 10-day periods) in assessi
the rainfall characteristics. It is emphasize
that the total seasonal or mean rainfall amoun
are often misleading in designing RWH sy
tems. This is exactly what is demonstrated b
the findings of this research. At the same tim
the difference in varieties grown on the tw
sites may also explain the large difference
crop performance between the sites.

The increase in yield from the small-cultivate
basin especially during *Vuli*, means that RW
assist in improving productivity of labour an
other inputs. For example, in Kisangara th
productivity of cultivated basin was increase
by a factor of 2.5 through RWH. This mean
that labour and inputs expended on this sma
area become more productive. The implicatio
of these findings is that a farmer with a RW
system with a CBAR of 2:1, cultivates an
uses inputs on only 33% of the field. Durin
Vuli, the cultivated area will produce more b
a factor of 2.5, almost compensating for wh
would be obtained from the area left as catc
ment. However, the farmer would benefit b
the fact that all the inputs were cut down
only 33% with only a small reduction in tot
harvest. On this basis, RWH leads to improve
productivity of inputs such as labour and fe
tilizer.

However, the increase was not large enough
compensate for the land used as catchme
area. This means that using micro-catchme
RWH for maize production may cause redu
tion in land productivity. This may not be a
ceptable in areas where there is scarcity
good land for cultivation.

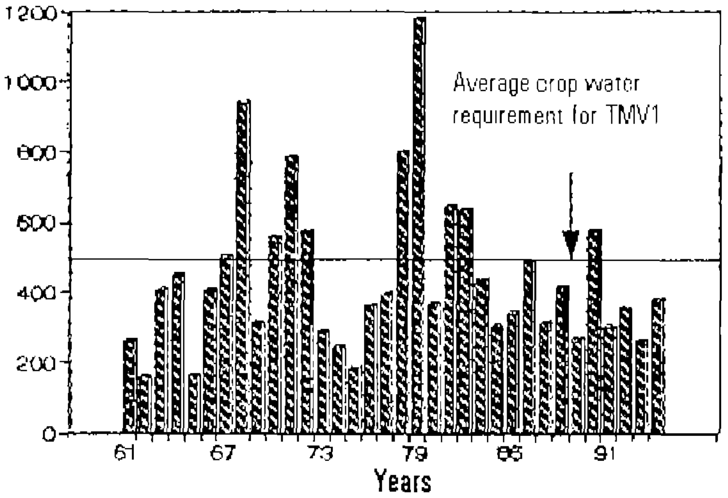
Table 5: **Effect of slope on grain yield**

Slope	Kisangara		Morogoro	
	Masika	*Vuli*	*Masika*	*Vuli*
8% (6%)[1]	2664.8	954.0	4355.3	-
3%	2866.0	514.1	4381.2	-
	**	**	**	

[1] Slope 6% was used in Morogoro experiments

** Not significant at P = 0.05

(a) Kisangara



(b) Morogoro

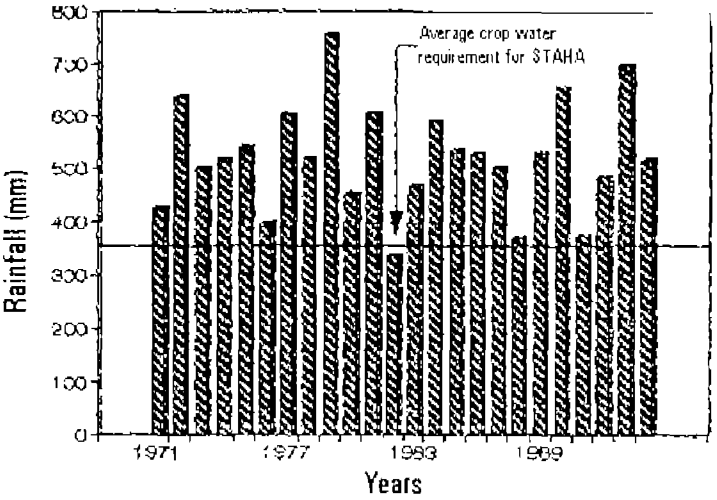


Figure 4: Comparison of historical *Masika* rainfall and average maize water requirement, in Morogoro and Kisangara

Seasonal effects

Season effects on grain yield was observed for both Kisangara and Morogoro sites. In Kisangara the grain yield was high during *Masika* with an average of 2,542 kgha^{-1} as compared to *Vuli* season with average yield of 734 kgha^{-1}. There was both significant difference between the season and treatment at P = 0.05 (Table 4). In Morogoro, grain yield was only harvested during *Masika*, where the average grain yield obtained in *Masika* season was 4,368 kgha^{-1} (Table 4).

Effect of slope

The effect of slope on grain yield was observe in Kisangara between 8% and 3 % slopes an in Morogoro between 6 % and 3 % slopes. I both sites the grain yield was slightly higher i the 3% slope (Table 5). This may be explaine by the difference in fertility due to removal o nutrients from the upper area and their deposi tion on the lower area. Another reason may b that the plots on 3% received water throug subsurface flow from the upper part.

Table 3: Effect of tillage practice on the grain yield

	MASIKA					*VULI*			
Site	Tillage Practice	1993	1994	1995	Mean	1993/94	1994/95	1995/96	Mean
Kisangara	FC	1844.3	3047.0	3159.0	2683.4	-	865.7	769.3	817.5
	SR	1209.7	2902.3	3091.3	2401.1	-	671.2	631.5	651.3
Morogoro	FC	4135.6	4990.1	-	4562.9	-	-	-	-
	SR	3980.3	4366.8	-	4175.6	-	-	-	-

Figures followed with similar letters are not significant at P = 0.05

Table 4: Seasonal effects on grain yield (kgha^{-1}) for Kisangara and Morogoro sites

Treatments	Kisangara [1]		Morogoro	
	Masika	*Vuli*	*Masika*	*Vuli*
T1	2502.3	361.3 b	4645.1	-
T2	2145.8	409.5 b	4228.7	-
T3	2779.2	1079.5 a	4512.1	-
T4	2406.8	616.0 ab	4648.1	-
T5	2768.8	1011.8 a	4531.4	-
T6	2650.7	928.5 a	3643.9	-
Mean	2542.3	734.4	4368.1	-

Figures followed with similar letters are not significant at P = 0.05

[1] At Kisangara, all treatments had significantly (P = 0.05) higher grain yield during *Masika* than the corresponding treatment in *Vuli*

constraint and the aim is to enhance productivity of labor and other inputs. Secondly, yield was calculated by taking into account the total mobilized land including the catchment area. This would be necessary in areas where land is a limiting factor. When only the cultivated basin is considered the yields generally increased with increasing CBAR ratio (Tables 2 a and b).

In Kisangara, for example, there was an increase of 17% for CBAR of 4:1 over the control, during *Masika*, while the increase during *Vuli* for the same CBAR was 152%. For Morogoro, during *Masika* there was a decline in yield probably due to too much water in the CB thus causing waterlogging problems.

When presented from the point of view of land productivity, the yield per unit of mobilized land decreased with increasing CBAR (Tables 2 a and b). In this case the total harvest from the cultivated area is expressed per ha of the land occupied by the RWH systems (i.e. CA + CB). The long term reduction in yield compared to control, during *Masika* in Kisangara was 53% and 77 % for CBAR of 2:1 and 4:1, respectively. During *Vuli* in Kisangara the long term mean reduction of yield is only about 27 and 50 % for CBAR of 2:1 and 4:1, respectively, compared to increase of 120 and 152 %. Therefore, during *Vuli* a net increase in long term mean of yields per unit inputs by about 100% was obtained in Kisangara. The yield from RWH treatments was significantly (P = 0.05) higher than from the control.

Cultivated basin management

At Kisangara, the management of the cultivated basin had some effect on the grain yield. The mean grain yield from flat cultivation was 2,683 kgha^{-1} and staggered ridges being only 2,401 kgha^{-1} (Table 3). The difference in yield was significant (P = 0.05) during only a few of the seasons.

Table 2a: Effect of RWH on long-term grain yield means at Kisangara

		CB area only		Total mobilized land	
	CBAR	Mean grain yield (kgha^{-1})	% Increase due to RWH	Mean grain yield (kgha^{-1})	% Decrease in yield
	0:1	2,324.1 a		2,324.1	
Masika	2:1	2,593.0 a	12	864.3	63
	4:1	2,709.8 a	17	542.0	77
	0:1	385.4 b		385.4	
Vuli	2:1	847.8 a	120	282.6	27
	4:1	970.1 a	152	194.0	50

Table 2b: Effect of RWH on long-term grain yield means at Morogoro

		CB area only		Total mobilized land	
	CBAR	Mean grain yield (kgha^{-1})	% Increase due to RWH	Mean grain yield (kgha^{-1})	% Increase due to RWH
	0:1	4,436.0 a		4,436.0	
Masika	2:1	4,580.1 a	3.2	1,526.7	65.6
	4:1	4,087.6 a	- 7.9	817.5	81.6

Figures followed with similar letters are not significant at P = 0.05

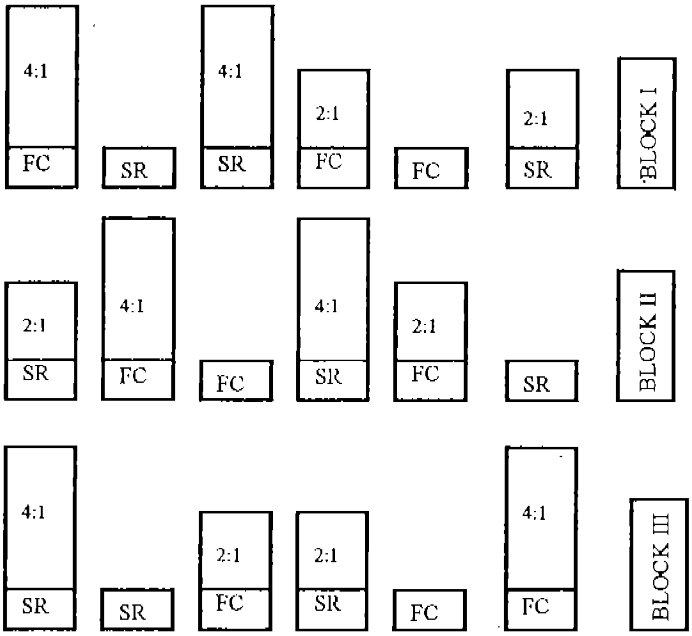


Figure 3: An example of treatments layout

Data collection and analysis

Data collected included daily rainfall (continuous and total), maximum and minimum daily temperature, pan evaporation, soil moisture content to a depth of 1.5 m, runoff from adjacent micro-catchments, agronomic data, such as biomass at six leaves and at silking stage and crop final harvest (biomass and grain yield).

Rainfall data was collected using a recording raingauge located at the Morogoro Meteorological station, about 0.5 km from the Morogoro site and at Kisangara, the recording raingauge was located 1.5 km from the site. This may have created some problems, as the rainfall in these areas is known to vary substantially over short distances (Ngana, 1991). To overcome this problem a non-recording raingauge was also used at the Kisangara site. Evaporation and temperature data was also collected for both sites. Moisture content was monitored using a neutron probe through an access tube in the centre of each CB. Cro growth was monitored through biomass harves at 6th leaf and at silking stages. Stover an grain yields were determined by harvesting 1 m^2 of well-bordered sample plots. All stove and grain were dried at 60°C until constan weight was obtained.

Descriptive analysis was used to compare long term means and seasonal effect on grain yield Analysis of variance (ANOVA) was used t test the effect of treatments on both biomas and grain yields.

Results

Effect of catchment to basin area ratio (CBAR) on grain yield

The grain yields as affected by the CBAR ar presented in two different ways. First by con sidering only the cultivated basin. This is valid approach in situations where land is not

Soils

The soils of the Morogoro sites are reddish brown sandy clay loam. The bottom soils are sandy clay, said to originate from metasediments of Uluguru Mountains. The soils are fairly deep (>100 cm), well drained and are classified as *Typic Ustorthent* (USDA soil taxonomy system) and *Eutric Regosols* (according to FAO/UNESCO system) (Kaaya, 1989).

The dominant soil occurring in the Kisangara experimental site is *Luvisol*. *Ferric Luvisol* occupies nearly 90% of the experimental site (Ngatoluwa *et al.*, 1995). These soils occur intensively on the middle and the lower slope position. *Ferric Cambisol* and *Plinthic Luvisol* cover approximately 8% of the experimental area. The remaining 2% is occupied by small pockets of *Chromic Luvisol*.

Experimental design, layout and treatments

The experimental layout was similar for both sites and in both cases was split into two different slopes of 3 and 8 or 6%. Randomized Complete Block Design (RCBD) with three replicates was used. The treatments were as elaborated in Table 1, and the layout was as shown in Figure 3. The Cultivated basins were 50 m^2 and were 10 m long and 5 m wide. The catchments were also 5 m wide, and the different CBAR were achieved by varying the length of the catchment. Maize (*zea mays* var TMV1) was used as a test crop for Kisangara and (*zea mays* var Staha) for Morogoro.

The crop was sown at a rate of two plants per hill. At sixth leaf growth stage, the crop was thinned to one plant/hill giving a plant population of 45,000 plants/ha with the spacing of 0.75 m between rows and 0.3 m between plants. Fertilizer TSP at a rate of 40 kg P/ha was applied at sowing, and N fertilizer was applied at rate of 40 kg N/ha at six-leaf growth stage. Tillage was implemented by hand hoe to a depth of 10 cm. A "U" shaped bund was constructed around each cultivated basin to a height of 15 cm. Ridges were constructed with staggered openings, for spreading harvested water.

Table 1: Description of treatments

Tillage practice on the CB	CBAR	Treatment
Flat cultivation (FC)	0:1	T1
	2:1	T2
	4:1	T3
Staggered Ridging (SR)	0:1	T4
	2:1	T5
	4:1	T6

equation:

$$\mathrm{CBAR} = \frac{\mathrm{CWR\ (mm)} - \mathrm{DR\ (mm)}}{\mathrm{DR\ (mm)} \times K \times \eta} \qquad (4)$$

Where:

- Crop water requirement (CWR) is defined as the depth of water needed for evapotranspiration (ET_{crop}). The maximum value of ET_{crop} is achieved when the crop is disease free, growing in large fields under non restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment (Doorenbos and Kassam, 1984). Crop water requirement is influenced by climate, crop type and stage of growth. It is estimated that the crop water requirements for maize cultivar TMV1 grown in Kisangara is 590 mm in *Vuli* and 500 mm during *Masika*. However, it is not possible for a crop in a farmers' field to meet the conditions for maximum ET_{crop}. This is why an efficiency factor (η) is introduced.
- Design rainfall (DR) is defined as the total amount of rain during the cropping season at or above which the catchment area provides sufficient runoff to satisfy the crop water requirement (Critchley and Siegert, 1991).
- Runoff coefficient (K) for a given period is calculated as:

  $$K = R_o/R_e \qquad (5)$$

  An analysis of the rainfall-runoff relationship and subsequent determination of runoff coefficients should be based on actual, simultaneous measurements of both rainfall and runoff. For example, parallel micro-catchments experiments carried out in Kisangara showed that runoff coefficient of 30% can be expected in bare compacted catchments.
- The efficiency factor (η) represents the proportions of water the plant can actually utilize, it varies from 0.5 to 0.75. The efficiency factor depends on the distribution of water in the field and consid losses due to evaporation and deep lation.

For Kisangara, the CBAR can be estim follows, using rainfall amount expected exceeded 70 % of the seasons, as desig fall:

CBAR (*Vuli*) $= (590 - 257)/(257 \times 0.3 \times$
$\approx 6{:}1$

CBAR (*Masika*) $= (500 - 318)/(318 \times 0.3 \times$
$\cong 2.5{:}1$

The main objective of this paper is to the effectiveness of micro-catchment sy in the performance of maize grown in arid areas.

Materials and methods

Location

The experiments were conducted in the s arid zones of Morogoro and Mwanga Distr In Morogoro, the experiments were loc within the Sokoine University Farm on lo tude $37^{0}39'$E and latitude 6^{0} 30'S and at an titude of about 500 m above mean sea l (masl). The site was close to the footslope the Uluguru mountains which descend abru to the gently undulating dissected penepl extending north and west of Morogoro. site was formally under maize cultivation several years before being left under fallow two years prior to start of the experiments 1993. In Mwanga District, the experime were located at Kisangara within the semi-a Western Pare lowlands (WPLL). The site w located at $37^{0}35'$E and 3^{0} 43'S at an altitude 870 masl. The area was under sisal producti since 1975. The sisal plants were cleared 1993 by a front mounted shear blade bulldoze before setting up the experiments.

The Catchment to Basin Area Ratio

The key requirement in the design of micro-catchment systems is to select an optimum value of the CBAR that will allow efficient run-off yield and optimum utilization of the water added to the CB. The key parameters can be presented as shown in Figure 2.

During a rainfall event, water balance on the CA is given by:

$$R_o = R_e - E_{CA} - I \qquad (1)$$

where:

R_o = surface run-off
R_e = effective rainfall
E_{CA} = actual evaporation from catchment area
I = infiltration

At the same time from the CB point of view, the most important parameter is the change of water stored in the root zone. Therefore, the water balance equation for the CB is given by:

$$\Delta_w = R_e + R_o - E_{CB} - D_p \qquad (2)$$

where:

Δ_w = change of water stored in the root zone
R_e = effective rainfall amount (assumed to be the same on both CA and CB)
R_o = run-on into the CB (= R_o from the CA)
E_{CB} = actual evaporation from the CB
D_p = water lost from the root zone due to deep percolation.

It is assumed that the water table is too low to affect this balance.

The ultimate goal is to optimize Δ_w. The approach to be taken is made clear by combining equations 1 and 2 into the following single equation assuming CA = CB (Boers *et al.*, 1986):

$$\Delta_w = 2R_e - E_{CA} - E_{CB} - I - D_P \qquad (3)$$

Therefore, a micro catchment RWH system should be designed to:

(i) Minimize infiltration and evaporation from the CA
(ii) Maximize infiltration on the CB while minimizing water lost to deep percolation
(iii) Minimize evaporation from water surface or bare soil on the CB.

The calculation of the CBAR is based on the concept: "*Effective water harvested = Extra water required by the crop*".

The Catchment to Cultivated Basin Area Ratio (CBAR) is calculated using the following

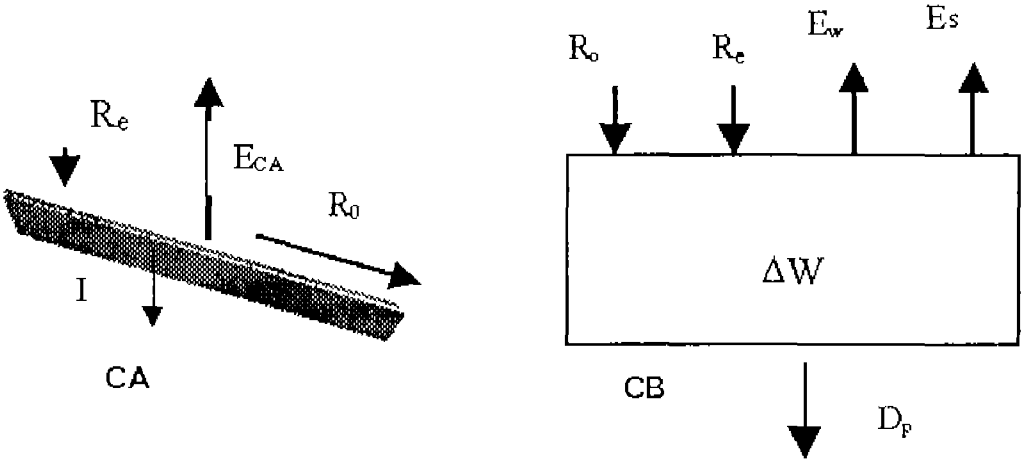


Figure 2: **Water balance components of the CA and CB (Modified from Boers *et al.*, 1986)**

been developed in different countries (Prinz, *et al.*, 1994, Reij *et al.*, 1988). All techniques have two major components; a Catchment Area (CA) and Cultivated Basin (CB) (Figure 1). The CA is always directly up-slope of the CB and the water flows directly to the basin for storage in the soil. The CA is treated and managed in ways that encourage the generation of high amount of run-off.

Runoff generation and conservation

The runoff yield of a catchment is a complex function of the characteristics of land surface, soil type and rainfall (Oweis *et al.*, 1999). Slope, length, cover and roughness are the most important characteristics. The length of a catchment has the most important effect on determining peak discharge, rise time, total runoff time and water harvesting potential. Runoff coefficient and peak runoff decreases with increasing catchment length although the total runoff from a large catchment is higher (Boers and Ben-Asher, 1982).

The vegetation cover and roughness encourag infiltration and reduce the runoff yield from given area. This is a consequence of depression storage that provides more time and opportunity for the evaporation and infiltration o the rainwater. The nature of the soil where th rain falls is a very important determinant o how much runoff can be expected. The mai controlling factors are infiltration rate, wate holding capacity and hydraulic conductivity o the soil.

The rate of infiltration and therefore runoff i also greatly affected by the rainstorm amoun intensity and distribution of rainfall. A hig amount will quickly saturate the soil and th excess will be released as runoff. High intensity rainstorms will lead to high runoff, because the intensity will exceed the rate of infiltration of the soil. Rain falling with long dr spells between storms will often reduce runo yield because the catchment will dry up durin the dry spell, and therefore the soil will be abl to absorb more of the rainfall received during subsequent storm.

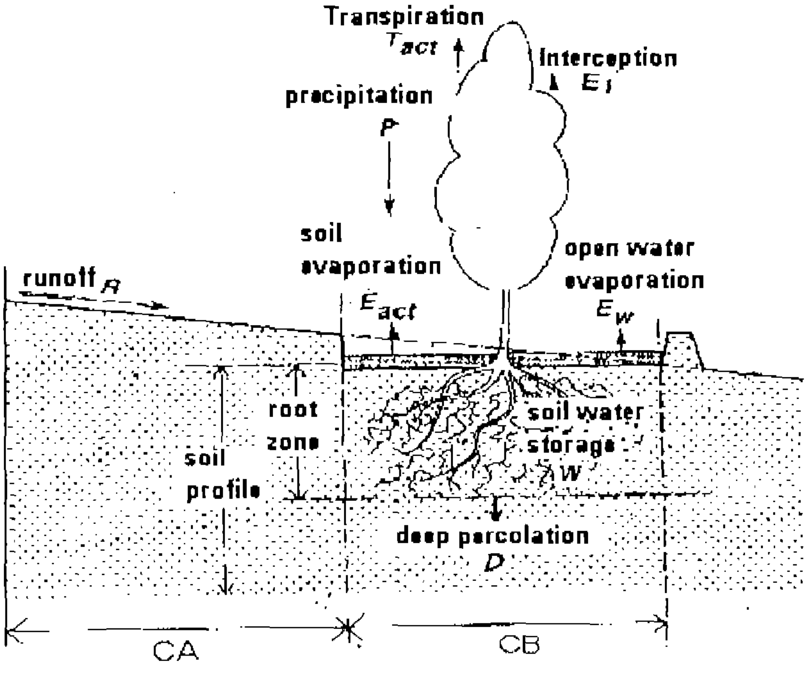


Figure 1: Interaction between the four facets of RWH (Boers, 1994)