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DESIGN, CONSTRUCTION AND EVALUATION OF RUNOFF WATER HARVESTING POND FOR SMALLHOLDER FARMING

Bayan Ahmed [1], Fikadu Gemeda [2]

[1] Oromia Agricultural Research Institute, Asella Agricultural Engineering Research Center Asella, Ethiopia.

ABSTRACT

For the reason of Rainfall shortage and variability constrain, crop production in Ethiopia is the main problem. For this supplementary irrigation by run off harvesting is strategic pathway to enhancing agricultural productivity and increasing smallholder farmers' income. Therefore, this study was conducted to Design, construct and evaluate runoff water harvested pond for supplementary irrigation on onion crop to addressing inherent crop failures under the rain fed agriculture due to mainly erratic rainfall. For this design, climatic and soil data were input to determine seasonal crop water requirement (CWR). The evaporation loss of water from water surface of pond was calculated. Then the performances of water harvested verses area irrigate were evaluated. Seasonal volume crop water requirement (CWR) of onion for farm area 2500 m2, evaporation loss of water from pond water surface of 121 m2 and total volume of seasonal water need were 382.05,53.38 and 435.43 m3 respectively. The geo-membrane laminated water harvester that has capacity of 223 m3 was designed and constructed. From on field performance shows, this volume of water harvested twice a year can irrigate 0.25ha by supplementary irrigation using water saving irrigation technology by treadle pump was produced 4.2 tone/ha. The investment, operation and production costs were 63,116, 1,125 and 6,675 ETH birr respectively. The total cost was 70,916 birr and growth return of 0.25ha was 15,750 birr/year (1050kg*15 birr/kg). This shows the farmer can return 22.21% of their investment cost. So, it is recommended to the government and non-government to initiate the farmers at lower stream of the catchment to harvest run off water and use for supplementary irrigation to increase their income.

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Corresponding Author

Bayan Ahmed, bayahm@gmail.com

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1. INTRODUCTION

Agriculture is the backbone of Ethiopian economy. It accounts for a little over 50 percent of the GDP, 90 percent of the total export revenue and employs 85 percent of the country's labor force and the main income generating sector for the majority of the rural population. It provides row materials for more than 70% of the country's industries CSA (Central Statistical Agency) (2013). The dependency of farming system on rain fed agriculture has made the Ethiopia's agricultural economy extremely exposed to weather and climate effects Conway and Schipper (2011). The failure of rain and the occurrence of drought or consecutive dry spells during the growing season zled to crop failure. This in turn results in food shortage and contributes to food insecurity and reduced income generation from agricultural products sale Teshome et al. (2010).

Rain-fed agriculture in Ethiopia is suffering from moisture stress which is a

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major limiting factor for successful crop production. Many of Ethiopian smallholders depending on rain-fed agriculture are food insecure. In many places, the amount of rainfall and the duration of rainy season are highly variable frequently resulting in low crop yields and associated low incomes. Because of large differences in rainfall distribution between years and within years coupled with short rainy seasons, rain-fed agriculture is very susceptible to water shortage. As the scarcity of water is rapidly increasing everyday particularly during the summer season, the demand for water also substantially increases Teweldebrihan (2014).

Water harvesting can best be described as all activities to collect available water resources, temporarily storing excess water for use when required, especially in periods of drought or when no perennial resources are available. The starting point is the collection of natural water resources from rainwater, fog, runoff water, groundwater or even waste water, which otherwise would have escaped. World water resources are facing dramatic changes as a result of global climate change, high water demands, population growth, industrialization and urbanization.

To respond to water scarcity and unequal distribution, small-scale water harvesting techniques provide a direct solution, especially in rural and drought-prone areas. Local storage of water is increasingly important for ensuring water availability and food security for rural and urban populations, especially in developing countries. This is particularly the case in areas with dry seasons where perennial rivers and fresh groundwater are not available or difficult to reach (NWP 2007).

The research conducted at semi-arid in Kenya (Machakos district) and Burkina Faso (Ouagouya) during 1998-2000 indicates a significant scope to improve water productivity in rainfed agriculture through supplemental irrigation, especially if combined with soil fertility management. The results were more promising on soils with higher water holding capacity on which crops seem to cope better with intra-seasonal dry spells Fox and Rockstrom (2000)

In Ethiopia, promotion and application of rainwater harvesting techniques as alternative interventions to address water scarcity were started through government-initiated soil and water conservation programmers.

Today, smallholder farmers feel increasing vulnerability to water shortages; consequently, the demand for water storage is rising. The more unreliable the natural supply becomes, the greater the need for water storage. With stored water accessible, farmers feel less vulnerable to climatic fluctuations, and thus are encouraged to invest more in agricultural inputs and equipment to improve their farming productivity Getachew (1999).

One of the main pillars of the Ethiopian government food security strategy is the development and implementation of water harvesting schemes mainly in the drought prone and chronically drought affected areas of the country. But most of farmers have not trained to harvest water and some of water harvester constructed was not depend on catchment run off and silt protector is not properly designed for this reason most of water harvested is filled by sediment.

Therefore, to minimize the negative impacts of runoff water generated from catchment area (erosion, flooding) and optimizing its benefits as supplementary source for addressing inherent crop failures under the rain fed agriculture due to mainly erratic rainfall this study was conducted with the objective of evaluating runoff water harvesting by supplementary irrigation on onion crops at Keta Barend Kebele.

2. MATERIAL AND METHODS

2.1. STUDY AREA

The study was conducted at West Arsi zone, Dodola district of Keta Barend kebele. The crop used for this study was red onion and treadle pump was used to transport water from harvester to irrigating field by over showering. The field area used for evaluation was 2500 m2.

2.2. DATA COLLECTION

The primary and secondary were collected. The data collected were farmers' estimations on direction of water flow, meteorological data; laboratory work was done to assess the soil physical and chemical property.

2.2.1. SOIL DATA

To determine the soil texture disturbed soil samples by auger and bulk density, moisture content at field capacity (FC) and permanent wilting point (PWP) undisturbed soil samples were collected by core sampler from two depths 0-30cm and 30-60cm at three points diagonally of the experimental site and were taken to laboratory for analysis.

2.2.2. CLIMATIC DATA

The minimum and maximum temperature, relative humidity, wind speed and daily sunshine hour of 20 years were collected from National Meteorological Agency to determine mean daily reference evapotranspiration (ETo) of the study area.

2.2.3. IRRIGATION WATER REQUIREMENT

CROPWAT version-8 was used and soil data and twenty years climatic data were fed to calculate the reference evapotranspiration (ETo) of the study area.

$$ETc = ETo \times Kc \tag{1}$$

Where: ETc = crop evapotranspiration (mm/day)

ETo = reference crop evapotranspiration (mm/day)

Kc = crop coefficient

2.2.4. SOIL INFILTRATION CAPACITY

Infiltration rate was measured using double ring infiltrometer. The measurement was done at 15,30,45,60-minute intervals at randomly selected study site.

2.2.5. RUN OFF COLLECTION

Due to site selected at the tail of large catchment the volume of run off collected was fixed by field to irrigate depending on crop water requirement need. To collect run off the rectangular canal and silt trap was constructed and diverted from flooding tail point of catchment.

2.2.6. SEDIMENT LOAD ANALYSIS

For sediment load determine, two methods were used and used for design water harvester volume of sediment (dead storage) determine. The first was during water harvest and second was after water harvested. For the first option one liter of runoff sample was taken from the inlet and outlet of the silt trap.

2.2.7. WATER LOSS/EVAPORATION

This lost water is referred to as consumed, because it is removed from the system. In some cases, this water consumption can be quite substantial. This will be calculated as stated by FAO (2015).

$$E = Kw*ETo \qquad (2)$$

where E is water loss/evaporated, Kw is the coefficient for open water, ETo is reference ET for short Grass. FAO (1998) suggests a Kw value of 0.65 at initial and 1.25 at development of the crop.

2.3. DETERMINATION OF THE STORAGE CAPACITY OF RWH POND

For determining volume of water harvester, sessional crop water and evaporation from surface water harvester and volume of sediment occupied was identified. Then truncated square pyramid formula was used.

$$\text{Volume: } V= (a2 +ab+b2)\ h \qquad (4)$$

$$\text{Lateral Area: } F=2(a+b) \qquad (5)$$

$$\text{Surface Area: } S=F+a2+b2 \qquad (6)$$

Where: b= the bottom surface of the pond

a= top surface of the pond and

h= the depth of the pond

2.4. LAMINATING AND FENCING

To prevent seepage loss, surface area of water harvesting pond was calculated using equation (6) and fitting geo-membrane plastic of 0.5mm was laminated. The fence was constructed to prevent the interference of animals and children.

2.5. PERFORMANCE OF WATER HARVESTED

The performance of water harvested was evaluated by theoretical irrigating capacity and on farm irrigating capacity of harvester depending on climatic and soil of the area, volume of sediment occupied, silt trap efficiency and water productivity

2.5.1. VOLUME SEDIMENT OCCUPIED

The silt passed the silt trap and entered harvesters were determined by area method after water used.

2.5.2. SILT TRAP EFFICIENCY (STE)

The silt trap efficiency of the reservoir is the ratio of sediment caught in the storage and total load entering with the runoff.

2.5.3. WATER PRODUCTIVITY (WP)

Is the ratio of the physical yield of a crop (kg) and the amount of water consumed (m3), including both rainfall and supplemental irrigation

$$WP = \frac{Yeild}{Amount\ of\ water\ consumed}$$

2.5.4. ECONOMIC ANALYSIS

Economic analysis was computed based on investment, operation and production cost of the experiment. The investment and operation cost was by adding material need for the contraction and cost of man power consumed during excavation and on field operation and production. The total gross return was obtained by multiplying yield with unit price of the product.

2.6. STATISTICAL ANALYSIS

The results were analyzed by descriptive statistically using Microsoft excel and compared averages result of parameters.

3. RESULT AND DISCUSSION

3.1. SOIL PHYSICAL AND CHEMICAL PROPERTIES

The laboratory result of soil physical and chemical properties at study site was presented in Table 1. From this table, the soil texture was clay and average soil bulk density was 1.13 g/ cm3. Field capacities (FC) and permanent wilting point (PWP) were 38.2 and 23.7 (%) respectively and total available water (TAW) was 145 mm/m.

Table 1 Soil physical and chemical property

Soil property	Results
Soil Particle size distribution	Sand (%) = 19 Silt (%) = 29 Clay (%) = 52
Texture	Clay
pH	5.8
EC	0.18
OC	2.26
OM	3.9
Bulk density (g/cm^3)	1.32
FC (% Vol)	38.2
PWP (%Vol	23.7
TAW (mm/m)	145

Infiltration rate (mm/hr)	8

OM=Organic matter, FC=Field Capacity, PWP=Permanent wilting point, TAW=Total available water

3.2. REFERENCE EVAPOTRANSPIRATION AND CROP WATER REQUIREMENTS

Table 2 shows daily and monthly reference evapotranspiration (ETo), effective rain falls and irrigation water requirements of onion crop at study area. This was used to determine volume of water harvested relation to area to irrigate. The minimum reference evapotranspiration was occurred 1.87 mm/day in December, maximum 4 mm/day in February and mean of 3.23 mm/day. The sessional reference evapotranspiration (ETo), effective rain falls and irrigation water requirements were 361.5, 107 and 254.6 mm respectively.

Table 2 Daily and monthly reference evapotranspiration (ETo), effective rain falls and irrigation water requirements of onion

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	3	Init	0.5	1.88	18.8	3.7	5.7
Dec	1	Init	0.5	1.87	18.7	6.1	12.6
Dec	2	Deve	0.61	2.28	22.8	4.7	18.1
Dec	3	Deve	0.82	3.07	33.8	6.8	27
Jan	1	Mid	0.99	3.71	37.1	9.8	27.4
Jan	2	Mid	1	3.77	37.7	11.7	26
Jan	3	Mid	1	3.85	42.3	11.5	30.9
Feb	1	Mid	1	3.93	39.3	10.7	28.6
Feb	2	Late	1	4	40	10.6	29.4
Feb	3	Late	0.94	3.78	30.2	11.9	18.4
Mar	1	Late	0.85	3.44	34.4	12.8	21.6
Mar	2	Late	0.77	3.16	15.8	6.8	9
Total					361.5	107	254.6

Kc= Crop coefficient, ETc =Evapotranspiration of the crop

3.3. WATER LOSS/EVAPORATION CALCULATION

The loss of water from upper surface area of water body was estimated using the equation 2 throughout session. Then the volume of water lost was considered as consumed on design. From the table 3 blow the volume of water lost due to evaporation from the surface of the body during crop growing season was 53.38 m3 was calculated.

Table 3 Water loss from water body of crop growing

Month	Average ETc (mm/dec)	Kw	Loss (mm)	Loss (m)	Area (m^2)	Volume of water (m^3)
Nov	18.8	0.65	12.22	0.01	121	1.48
Dec	18.7	0.65	12.155	0.01	121	1.47
Dec	22.8	1.25	28.5	0.03	121	3.45
Dec	33.8	1.25	42.25	0.04	121	5.11

Jan	37.1	1.25	46.375	0.05	121	5.61
Jan	37.7	1.25	47.125	0.05	121	5.70
Jan	42.3	1.25	52.875	0.05	121	6.40
Feb	39.3	1.25	49.125	0.05	121	5.94
Feb	40	1.25	50	0.05	121	6.05
Feb	30.2	1.25	37.75	0.04	121	4.57
Mar	34.4	1.25	43	0.04	121	5.20
Mar	15.8	1.25	19.75	0.02	121	2.39
		Total				53.38

3.4. DESIGN OF WATER HARVESTER

For determining volume of water harvester, sessional crop water and evaporation from surface water harvester and volume of sediment occupied. For determining volume of water harvester, sessional crop water and evaporation from water surface were 382.05 and 53.38 m^3 respectively. The total volume of water used for design of harvester was 435.43 m^3

Table 4 Total volume of water pond

Month	CWR (mm)	Irrigated area in (m^2)	Volume of water need in (m^3)	Volume of water loss in (m^3)	Total volume of water in (m^3)
Nov	5.7	1500	8.55	1.48	10.03
Dec	12.6	1500	18.9	1.47	20.37
Dec	18.1	1500	27.15	3.45	30.6
Dec	27	1500	40.5	5.11	45.61
Jan	27.4	1500	41.1	5.61	46.71
Jan	26	1500	39	5.70	44.7
Jan	30.9	1500	46.35	6.40	52.75
Feb	28.6	1500	42.9	5.94	48.84
Feb	29.4	1500	44.1	6.05	50.15
Feb	18.4	1500	27.6	4.57	32.17
Mar	21.6	1500	32.4	5.20	37.6
Mar	9	1500	13.5	2.39	15.89
	Total		382.05	53.38	435.43

But 223 m^3 the harvester that have the bottom surface of 6 m top surface of 11 m and depth of 3 m the pond was designed and to make this study more economical the water harvester capacity decreed by two-fold and water harvesting made at two times. Its lateral surface area was laminated by 238 m2 geo-membrane.

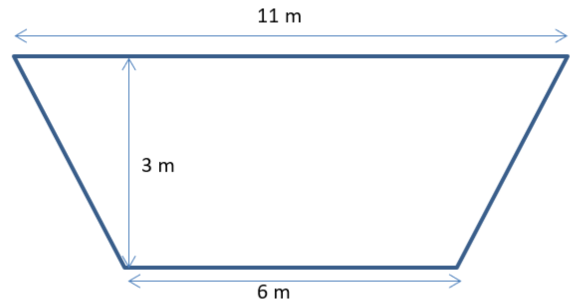

Fig 1 Size of designed water harvester

Fig 2 Water harvester pond constructed

3.5. WATER PRODUCTIVITY (WP)

The was calculated using yield of 4200kg /ha and sessional water requirement of 4500 m^3/ha was 0.93kg/m^3

3.6. ESTIMATION OF COSTS FOR A RUN OFF HARVESTER WITH 223 M3 CAPACITY

The following Economic analysis was computed based on investment, operation and production cost of the experiment. The total investment, operation and production cost was 63,116 ETH birr.

Table 5 The investment cost of water harvesting pond

Materials	Quantity	Unit cost in birr	Total cost in birr
Excavation	223 m^3	150	33,450
Geo-membrane plastic 0.5mm	238 m^2	65	15,470
Geo-membrane binding	238 m^2	42	9,996
Fence wire	36 kg	60	2160
Nail 3, 5,7,9	3 kg	30	90
Kanch	55 pcs	20	1100
korkora	1 pcs	100	100
Daily lobar fence constriction	10	75	750

Total cost			63,116
Operation/session			
Water lifting by Treadle pump	15	75	1125
Total			1125
Production for 0.25 ha			
Land preparation	2 time	500	1000
Seed	Bed	800	800
Fertilizer	1.5 kunt	1500	2250
Cultivation	10	75	750
Chemicals			1500
Harvesting	5	75	375
Total			6,675
Over all total cost			70,916

3.6.1. NET RETURN COST

This capacity of harvester was irrigating 0.25 ha/year and its total cost was 70,916 birrs. The growth return of 0.25ha was 15,750 birr (1050kg*15 birr/kg). This shows the farmer can return 22.21% of their investment cost.

4. SUMMARY, CONCLUSION AND RECOMMENDATIONS

4.1. SUMMARY AND CONCLUSION

Supplementary irrigation by run off harvesting is strategic pathway to reduce poverty in rural drought prone areas for enhancing agricultural productivity and boosting farm income.

For the study to Design, construction and evaluation of runoff water harvesting Pond for supplementary irrigation the climatic and soil data were input to determine seasonal crop water requirement of onion and evaporation loss of water from water surface.

From the result obtained the Seasonal volume of crop water requirement of onion for farm area 2500 m2 and evaporation loss of water from water surface of 121 m2 and total volume of seasonal water need to irrigate this area were 382.05,53.38 and 435.43 m3 respectively and used for the design. The geo-membrane laminated water harvester that has capacity of 223 m3 (6 m bottom width and 11 m top width) was designed and constructed.

Then the performances of water harvested verses area irrigate were evaluated. From on field performance shows, this volume of water harvested twice can irrigate 0.25ha by supplementary irrigation using water saving irrigation technology (treadle pump) by over showering and was produced 4.2 tone/ha.

4.2. RECOMMENDATION

The extension team has work to initiate the farmers at lower stream of the catchment to harvest run off water and use for supplementary irrigation to increase their income.

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