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Determination of Different Lining Materials for Reducing Seepage Loss in Water Harvesting Structures at Arsi Zone, Ethiopia

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Abstract:
Water harvesting has been practiced for many years in several regions globally and is mainly used for domestic and agricultural purposes. Seepage losses through soils have a great influence on the performance of water harvesting structures. The experiment was conducted at Kulumsa Agricultural Research Center to identify the best efficient lining material for a water harvesting pond. The experiment was conducted for two consecutive years during the off-season. Four treatments (mortar, ash, compaction alone, and bentonite) were used in a randomized complete block design (RCBD) with four replications. The overall analysis of the data showed a highly significant difference among the treatments. The overall findings of the study indicated that the use of various lining materials had a significant impact on seepage loss control (P 0.05). The maximum seepage rate of 19.50 cm/day was observed at T1 (compaction alone treatment), and the lowest seepage rate of 11.13 cm/day was found at treatment using T4 (bentonite). The seepage rate observed at T4 (bentonite) was 42.92% lower than the highest seepage rate at T1 (compaction alone). The physical seepage rate analysis shows that bentonite was the best lining material to control water loss from water harvesting structures and store water for a longer period than other treatments. As a result, bentonite was recommended to control water loss from water harvesting structures in similar soil types based on the lowest seepage rate.

Keywords: Lining Material, Pond, Water harvesting and Seepage loss

INTRODUCTION

Ethiopia has tremendous water resource potential as compared to many African countries. It has a mean annual rainfall of about 1090mm even though it is unpredictable and increasingly erratic. About 110 billion cubic meters of valuable surface water is lost from the country annually (Rami, 2003). This huge sum of untapped resources can be valuably used for the enhancement of agricultural production if a proper mechanism is developed for its storage and utilization. On the contrary, irrespective of this striking water potential, large-scale dams, and irrigation projects are not extensively constructed in the country. This is due to the costly nature and inherent large capital investment requirement of such projects. Hence, the federal government developed water harvesting schemes which can be adopted at the household level with relatively cheaper costs using household labor. As a result, water harvesting tanks and ponds were proposed as practical and effective alternatives. Supplemental irrigation can be made possible by making use of stored rainwater to mitigate moisture stress and sustain agricultural production at the household level. This in turn makes farming families less vulnerable to drought and less reliant on outside assistance (Rami, 2003).

Harvested water for irrigation needs to be managed and used efficiently (Panigrahi et al., 2001; Fox and Rockstrom, 2003). Water harvesting improves overall production, improves environmental quality, reduces cropping risk, and enhances food sufficiency. The importance of managing harvested water to increase overall food production to alleviate famine in many areas of the developing world has to be institutionalized (Prinz, 1994; Yuan et al., 2003).

To bring sustainability to rural economies, water harvesting techniques and community-based small-scale irrigation schemes are considered strategic development initiatives (Li et al., 2004). Irrigation scheme development should be done at various levels using different alternative water sources. This may require the diversion of rivers, construction of macro and micro dams, and the establishment of water harvesting structures at the household level (Awulachew et al., 2005). A large number of waters harvesting technologies have also been implemented with support from the Government of the Federal Democratic Republic of Ethiopia. For instance, an assessment indicated that more than 300,000 shallow wells, about 206,200 household level structural ponds, 49,311 community ponds, 5,635 cisterns have been constructed and a total of 32,727 springs have been developed (FDRE, 2000).

According to Goshu, 2007, for countries with erratic and poorly distributed water harvesting, reservoirs/ponds are proving to be a promising answer to the problem of storing water to supplement agricultural production and other uses. The major challenge the country is facing in this regard is collecting and storing the resource when it falls as rain, and efficient distribution and utilization when the rain stops (Rami, 2003). The most critical of all the problems is the water loss due to seepage resulting from poor lining materials of the harvesting storage structures (Rami, 2003 and Tafa, 2002).

Hence technologies providing good protection against seepage loss have been given a priority (Rami, 2003, Goshu, 2007). In a view of this, some research works have been conducted to identify the best lining materials that substantially reduce water loss due to seepage. Various sealant materials like cement, bentonite, polythene lining, brick lining, stone slab lining, and a few chemicals based on sodium have been tried and found effective. The study conducted by Mahtsente and Kidist (2019) at the Holeta catchment shows that bentonite has the least seepage rate and can hold water for a longer period. The physical analysis indicated that bentonite performs best in harvesting water for a longer period and minimizing seepage loss under the bed of the water harvesting structures. In many parts of the country, seepage loss reduction is mainly believed to be made possible by lining the surfaces of storage structures with geo-membrane (thick plastic sheet), reinforced mortar, and compaction. The first two methods are effective but too costly to be afforded by a resource-poor or even a medium-income level of farmers. Compaction is less effective to meet required demand at the household level (Goshu, 2007). Some other lining materials can be tested for reduced seepage loss and further selected and subsequently promoted under farmers' conditions. Therefore, this study was designed to quantify the storage efficiency of the water harvesting structure and select bet lining material for seepage loss control under the water harvesting pond in the study area.

MATERIALS AND METHODS

Description of the Study Area

The research was carried out at the Kulumsa Agricultural Research Center in Tiyo district, Arsi Zone, south-eastern Ethiopia. Geographically, the study area is located between 8° 00' 591" N latitude and 39° 09' 25" E longitude, at an elevation of 2195 m a.s.l. The study area has a unimodal rainfall pattern with an annual mean rainfall of 809 mm and minimum and maximum air temperatures of 9.90 and 23.080 degrees Celsius, respectively. The soil type at the experimental site is clay loam, with a bulk density of 1.25 g/cm3.

Treatment Setup and Experimental Design

The experiment has four treatments of different lining materials such as T1 (soil compaction alone), T2 (mortar), T3 (ash or local heater), and T4 (bentonite). The experiment was designed as a factor experiment in a randomized complete block (RCBD) arrangement with four replications. A 17m by 14m experimental field was cleared and prepared. The experimental site has a slope of less than 1%. A total of sixteen square-shaped ponds were excavated. Each pond has $1m^3$ storage capacities and is arranged 3m apart to avoid lateral flow. The ponds were dug with soil formation and the sides of all ponds were covered by plastic sheets to manage lateral water movement. The pond was covered with Geomembrane to protect against evaporation loss and prevent any unnecessary addition of water from the rain or runoff,

Treatment Preparation

Mortar:

The loosened soil was compacted to a dense, tight layer with a manual compactor of 15Kg to a depth of knee height. The number of drops of manual compacter was made to about 200 times for each pond. The thicknesses of the compacted layers were 0.1m. After compaction, the base was lined with mortar for a thickness of 0.02 meter as the first coating and screed for a thickness of 0.01 meter as the second and last coating. The surface of the plastered structures was covered by sack and water spread two times a day for five days and made ready for wetting after 7 days of refilling the water.

Ash:

Local heater (ash) was collected from local households that use to consume cow dung, crop residue, and eucalyptus wood as firewood. The ash was spread over the bottom of the ponds and compacted with a manual compacter to a thickness of 0.1m.

Compaction Alone:

The ponds were wetted to the optimum moisture content and compacted to a dense, tight layer with a manual compacter. The thickness of the compacted layer was 0.1m. The compacted ponds were left free until the first wetting.

Bentonite:

The loosened soil was compacted to a dense, tight layer with a manual compactor of 15kg to a depth of knee height. The thicknesses of the compacted layers were 0.1m. After compaction, the base of the ponds was lined with bentonite to a thickness of 0.02m.

Data Collection and Statistical Analysis

Data Collection:

The seepage rate of each pond was collected daily within 3 hours difference to quantify the amount of water leaked from the water harvesting ponds. The measurement has performed using a ruler. After the depth of water is recorded, the seepage rate (cm/day) was determined using the following equation:

$$S = \frac{V}{A} \qquad \text{eq. (1)}$$

Where, S=Seepage rate (cm/day), V=Volume of water seeped (cm^3/day), A = Wetted surface area of the pond (cm^2)

The volume of water was determined as:

$$V = \frac{\Delta h}{2}\left(A_i + A_{ii}\right) \qquad \text{eq. (2)}$$

Where, V=is the volume of water seeped (cm^3/day), Δh=is Change in-depth within 24hrs (m), Ai and A_{ii} are an area of water surface in two consecutive days

The mean wetted surface area of the ponds (A) is determined as:

$$A = \frac{A_i + A_{ii}}{2} \qquad \text{eq. (3)}$$

Where A_i and A_{ii} are the wetted surface area of the pond on two consecutive days.

Statistical Analysis

Analyses of variances for the data recorded were conducted using SAS statistical software for the least significance difference (LSD) test at 5% probability used for mean separation when the analysis of variance indicated the presence of significant treatment differences.

RESULT AND DISCUSSION

The daily based collected seepage rate data of two years showed a significant difference among treatments. The result of the analysis was summarized and presented for each parameter.

Seepage Rate Analysis

The result of this study indicated that there was highly significant variation in seepage rate among treatments of different lining materials application to water harvesting ponds. The maximum seepage rate of 19.50cm/day was obtained at T1 (compaction alone) treatment and followed by T2 (Mortar) with the value of 15.21cm/day. The minimum seepage rate of 11.13cm/day was observed from T4 (bentonite) followed by T3 (Ash) 14.95cm/day. This study shows that bentonite has the capacity to save 42.92% of irrigation water than the control from water harvesting structure. On the other hand, mortar control about 22% more water than compaction alone treatment. This result was agreed with (Silva and Uchida, 2000) pore plugging and cement like structure in turn impedes water flow and water infiltration into the soil.

Mahtsente and Kidist, 2019 also reported that the seepage rate of treatment 4(Bentonite) is 37.60cm/day which is about 58% lower than Control treatment (compacted alone soil). Therefore, based on the seepage rate and storage capability, bentonite performs more efficiently than the other lining materials tested.

Table 1: Effect of different lining materials on daily seepage rate of water harvesting pond

Treatment	Depth of Seepage (cm/day)
T1= Compaction Alone	19.50[a]
T2= Mortar	15.21[b]
T3 = Ash (Local Heater)	14.95[b]
T4 = Bentonite	11.13[c]
$LSD_{0.05}$	**3.71**
CV (%)	**1.53**

CONCLUSION AND RECOMMENDATION

This Experiment was conducted in Kulumsa Agricultural Research Center on clay loam soil type during the year 2015/2016 and 2016/17 with an objective to identify the best efficient lining material for water harvesting pond. In this study four lining materials (compaction alone, Ash, Mortar and Bentonite) were evaluated in terms of the capability to control seepage rate of water harvesting pond. The analysis of variance was conducted using SAS statistical software. The seepage rate analysis result of different lining materials shows that, bentonite has capacity to reduce seepage loss of 42.92%, 27% and 26% than Compaction alone, Mortar and Ash, respectively. Following bentonite mortar was given comparatively good performances on seepage losses control. Compaction alone and mortar were given the least in seepage loss control respectively. Generally, this study can be concluded that bentonite was preferable in the study area based on the seepage loss control capacity.

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