Research Journal of Finance and Accounting
ISSN 2222-1697 (Paper) ISSN 2222-2847 (Online)
Vol.14, No.9, 2023

Economic Importance of Different Sealant Materials for Seepage Loss Control of Water Harvesting Pond under Irrigated Condition

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Abstract
This study was carried out in order to identify low-cost and efficient sealant materials for water harvesting ponds. An extensive cost comparison study of sealant materials was conducted, taking into account seepage reduction and farm income loss. Four seepage control materials were evaluated in terms of their financial cost. The cost analysis was conducted in terms of farm income loss when three crops' water productivity (kg/m^3) were considered potato, onion, and wheat; 1.13, 10.57 and 5.27 kg/m^3 of wheat, potato and onion, respectively. The cost of sealant materials includes the capital cost of material and labor for purchase and application in water harvesting ponds. The cost-benefit analysis result of sealant materials (compaction, mortar, ash, and bentonite) were compared for the next ten years and gave a significant farm income. For this study a water harvesting pond having a volume of 4,792 m^3 was considered to cultivate (wheat, potato, or onion) for one cropping season under irrigated conditions. A farm pond managed by; bentonite and Ash can save 23 % and 43 % than control treatment respectively. The saved irrigation water used to cultivate wheat, potato, and onion crops in 1 ha of land for one cropping season can bring an additional farm income of about 317,632 ETB with Bentonite and 226,798 ETB with Ash when compared to the compaction alone treatment (control). Analysis of cost and income over ten years productivity period showed that, the maximum cost of sealant materials to cover a volume of 4,709.69 m^3 requires at least four years investment period to achieve the breakeven point (189,600 ETB), that corresponds to the point at which the cost of sealant materials equals the resulting farm benefits. Therefore, investing in sealant materials for control seepage lose from water harvesting ponds will give a profit of their investment after four and above project years.
Keywords: Cost Effective, Sealant Material, Water harvesting, Water loss
DOI: 10.7176/RJFA/14-9-01
Publication date: May 31st 2023

INTRODUCTION

Rainwater is the most important source of fresh water and there is need to manage the rain water so as to reduce the impact of moisture stress and obtain sustainability in agricultural production (Ghanshyam, et al. 2020). Water scarcity will progressively constrain food production growth and causing adverse impacts on the goals of food security and human well-being at the alarming rate (Rosegrant, et al. 2009). A major reason for the low and erratic rate of growth in agricultural production is uncertainty and unpredictable rainfall, combined with low soil fertility. Even in years of 'average' rainfall, a shortfall during critical periods of crop growth often leads to widespread crop failure. Therefore, water storage is absolutely crucial for stabilizing and increasing crop yields (FAO, 2003).

The concept water harvesting has been defined in various ways and scholars. The terminology of water harvesting is used to indicate the collection and management of floodwater or rainwater runoff to increase water availability for domestic and agricultural use as well as ecosystem sustenance (Mekdaschi Studer, R. and Liniger, H. 2013). Water is harvested and directed either directly into crop fields or into various types of natural or man-made storage structures. A large variety of storage technologies are used in Eastern and Southern Africa and many of these are described and illustrated in (Ngigi, S. N. 2003 and Mati, B. M. 2006). In any given location, the impact of different types of storage on poverty can vary significantly, with some options being much more effective in reducing poverty than others (Hagos, et al. 2012). Sufficient investment in water harvesting needs to be not only a higher priority for the semiarid regions, but also for the entire country (Kidane W/G\Giorgis, 2001). Farm ponds and reservoirs provide a logical source of such water; they may be designed and adjusted to fit the individual land use plan (Taffa Tulu, 2002).

In Ethiopia, many water harvesting structures have been constructed. The most critical of all the problems is the water loses due to seepage resulting from poor lining materials of the storage structures (Rami, 2003; and Tafa, 2002). Seepage takes place at the bottom as well as sides of farm ponds. It is normally high in sandy soils while it is low in loamy to clay soils. Further, seepage losses are higher in initial years of construction while it reduces slowly in one or two years due to normal siltation of clay particles coming along with the run-off water. Various sealant materials like cement, bentonite, polythene lining, brick lining, stone slab lining and few chemicals based on sodium have been tried and found effective. Normal water loss rate of 0.25cm per day is tolerable for farm ponds (Ashwani et al., 2010).

The water loss due to seepage from the earthen type pond can be controlled at high level by applying various techniques; such as: converting earthen to concrete pond; thick clay lining of pond; poly-lining of pond. Further, converting earthen into concrete pond is a costly venture that cannot be afforded by poor farmers, while clay-lining of earthen pond is very cheap method for reducing water loss due to seepage. But the problem with this, clay-lining pond is that in case of earthquake, the pond may get cracked resulting further water loss. Several researchers, like Kumar et al. (2007), Srivastava and Bhatnagar (1989) suggested plastic lining of water bodies to increase water holding capacity for fisheries and other purposes.

According to the study conducted by Mahtsente and Kidist (2019) at Holeta catchment, use of mortar costs higher (1,706.33 ETB/$m^{3)}$ and compaction alone costs low (150 ETB/m^3). The cost analysis for lining material showed that mortar costs higher during execute of the experiment years and the cost of compaction were the least. Comparing the installation cost, bentonite is not the least price but it is about 75% less than the highest price.

There are also some other lining materials that can be tested for reduce seepage lose and subsequently promoted under farmers conditions. In this regard, uses of salt and household heater ash are among preferable materials used elsewhere in the world. With proper planning, site and suitable water harvesting technology selection, and installation, water availability at each plot of land can be maximized through adoption of water harvesting schemes at household level (Rami, 2003). Therefore, the general aim of this research was to identify low cost and efficient sealant material for water harvesting structure.

RESEARCH METHODOLOGY

Considering seepage loss of each pond to quantify the amount of water leaked from the water harvesting ponds. The calculation has performed using a ruler and converted to a volume of water used to cultivate wheat, potato and onion under irrigated condition. The volume of water loss (m^3/day) from the ponds was considered as an opportunity cost which could cultivate certain amount of land under irrigated condition.

Sealant materials considered for seepage lose control

The study estimates all the relevant costs and benefits and compares net irrigation benefits under four different seepage control sealant materials for water harvesting pond; use of soil compaction, covering the internal surface area using mortar, use of ash and bentonite as sealants in farm ponds. The net farm income is estimated when farmers continue with the existing water management practices and choose the option to store water in water harvesting ponds.

Data Analysis

Economic analysis of the sealant materials was performed to the investment required for its implementation, the benefits that it will bring, to determine the Net Present Value (NPV), and Payback Period (PB) for each sealant material. Costs in terms of investments of storage pond for irrigation purpose was considered. The full calculation of the present value is assumed to the present value of all 10 years future cash flows, minus the investment cost (materials +labor cost).

$$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t}$$

Where: R_t = Net cash inflow-outflows during a single period t, i = discount rate or return that could be earned in alternative investments, t =Number of times periods

RESULT AND DISCUSSION

Water storage farm pond under different sealant materials for seepage lose control

The study result of Mehiret et al., 2022 indicated that soil compaction alone has significantly higher seepage losses than other treatments. The maximum volume of water 918.39 m^3 was loss from soil compaction alone treatment of water harvesting pond and which was followed by mortar with the value of 716.34 m^3. The minimum water loss of 541.42 m^3 was observed from bentonite followed by ash at 704.10 m^3 due to the capacity of bentonite to control seepage loss from farm pond. The reported of Mahtsente and Kidist, 2019 confirmed that the seepage rate of Bentonite is about 41% lower than compacted alone soil. Bentonite saved 376.97 m^3 more water than the control experiment (compaction alone). This means with the additional water saved, farmers have a choice to irrigate additional land with wheat, potato and/or onion or some combination of the two crops that yields the highest returns. The study conducted at Holeta catchment by Mahtsente and Kidist, 2019 for the determination of cost-effective sealant material also confirmed that the seepage rate of bentonite treatment 58 % more efficient than the other lining materials tested.

Table 1: Farm price loss, TFC (material and construction) cost of sealant materials for farm water harvesting structure

Treatments	Crop	Seepage loss (%)	Average Water Productivity (kg/m³)	Crops Seasonal water requirement (m³/ha)	Water loss per cropping season (m³)	Crops market price per kg (ETB)	Loss farm income due to seepage (ETB)	Total Fixed Cost (ETB)
Soil Compaction	Potato	19.50	10.57	4400.00	858.00	25.00	226,726	42,000
	Onion		5.27	5474.00	1067.43	35.00	196,887	
	Wheat		1.13	4255.00	829.73	40.00	37,503	
Average				**4,709.69**	**918.39**		**153,705**	
Mortar	Potato	15.21	10.57	4400.00	669.24	25.00	176,846	144,000
	Onion		5.27	5474.00	832.60	30.00	131,633	
	Wheat		1.13	4255.00	647.19	35.00	25,596	
Average				**4,709.69**	**716.34**		**111,358**	
Ash	Potato	14.95	10.57	4400.00	657.80	25.00	173,823	84,000
	Onion		5.27	5474.00	818.36	30.00	129,383	
	Wheat		1.13	4255.00	636.12	35.00	25,158	
Average				**4,709.69**	**704.10**		**109,455**	
Bentonite	Potato	11.13	10.57	4400.00	489.72	25.00	129,408	189,600
	Onion		5.27	5474.00	609.26	30.00	96,323	
	Wheat		1.13	4255.00	473.58	35.00	18,730	
Average				**4,709.69**	**524.19**		**81,487**	

Cost Comparison of sealant materials

The total labor and material required for each pond is indicated in Table 2. A trapezoidal farm pond having a dimension of Top length 50m, Top width 45m, side slope 2:1, depth 4m, free board of 0.5m and bottom surface area of 34*26 m², and holds 4,792 m³ of water was considered for this study. Bentonite clay experiment recorded a higher investment cost of pond construction is 189.600 ETB/pond. This is due to bentonite was not easily available in the market and their cost is also high as compared to the other sealant materials. On the other hand, soil compaction alone was recorded as lower cost 42,000 ETB/Pond, followed by ash and mortar 84,000 and 144,000 ETB/Ponds. The sum of all labour and material costs were the costs of one pond during the experimental season. As can be seen from figure 1 soil compacted alone pond results the cheapest birr/pond as compared with other sealant materials and followed by ash.

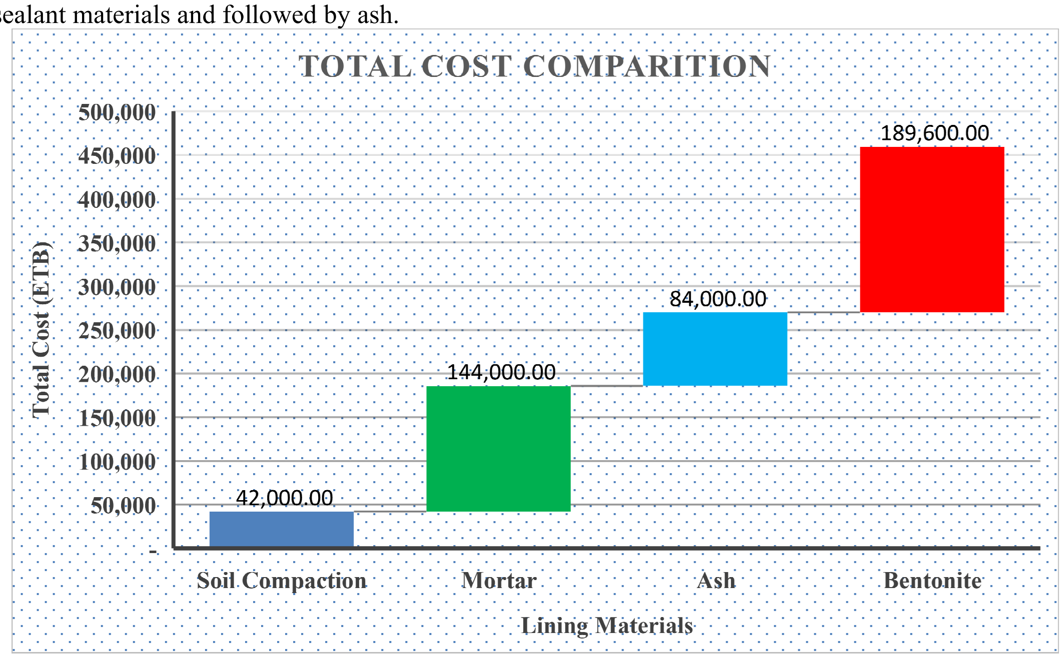

Figure 1: Cost comparison of sealant materials

Cost-Benefit Analysis of sealant materials

Cost-Benefit Analysis of water harvesting farm ponds treated with different seepage controlling materials (soil compaction alone, mortar, ash (local heater), and bentonite) have been evaluated in terms of their cost of investment. The cost of seepage controlling materials includes the capital cost of material and labor for construction of ponds. The opportunity cost of lost water through seepage from water harvesting pond is the forgone farm benefits. Seasonal or annual lost income from water losses is calculated as the net income in ETB/m^3 times the quantity of lost water seasonally due to seepage losses. The study result of Samuel et at., 2019; Lindi et al., 2018 and Mehiret et al., 2021 showed the water productivity of 1.13, 10.57 and 5.27 kg/m^3 of wheat, potato and onion has been found in the study area, respectively. The price of each crop was estimated based on water productivity (kg/m^3) of wheat, potato and onion crops, see (Table 2).

Assume the seasonal cash flows are earned at the end of the cropping season. This is a future payment, so it needs to be adjusted for the time value of money. To illustrate the concept of cash income, loss of the first 10 years payments is displayed in table 2. In this analysis an irrigated land of 1 ha is considered with potato, onion and wheat crops under off season irrigated condition. The potato and onion crops have the highest and wheat has relatively low return per a given m^3 of water used. Net present value of farm benefits is estimated using NPV function for 10 years with a 7 % discount, as shown in Table 2.

Considering the three-seepage reduction material for water storage ponds and management options this study compares the NPV of the three-seepage controlling material with respect to the compaction alone experiment as a check in water storage farm ponds. A long-term trajectory of discounted costs and discounted benefits of four seepage controlling options were expressed as net present value. Figure 2 shows the Net Present Values (net farm incomes loss) of the four water storage management options over 10 years. The results of the cost-benefit analysis indicate that bentonite is financially viable to implement in the study area. Bentonite will provide higher farm benefits than cement mortar and ash for the purpose of pond and irrigation water management.

Table 2: Cost-Benefit Analysis of soil compaction alone, mortar, ash and bentonite over the next 10 years

Years	**Farm income losses due to seepage (ETB)**				**Cost saved due to seepage control (ETB)**		
	Compaction	**Mortar**	**Ash**	**Bentonite**	**Bentonite**	**Ash**	**Mortar**
	A	B	C	D	(A-D)	(A-C)	(A-B)
1	143,650	104,073	102,294	76,156	67,493	41,355	39,576
2	277,902	201,338	197,896	147,330	130,572	80,006	76,564
3	403,372	292,240	287,244	213,848	189,524	116,127	111,132
4	520,634	377,195	370,747	276,014	244,619	149,886	143,438
5	630,224	456,592	448,787	334,114	296,110	181,436	173,631
6	732,645	530,795	521,722	388,412	344,232	210,922	201,849
7	828,365	600,144	589,885	439,158	389,206	238,479	228,220
8	917,823	664,956	653,589	486,585	431,238	264,234	252,867
9	1,001,429	725,527	713,125	530,909	470,520	288,303	275,901
10	**1,079,565**	**782,137**	**768,767**	**572,333**	**507,232**	**310,798**	**297,428**
TFC	**-**	**144,000**	**84,000**	**189,600**	**189,600**	**84,000**	**144,000**
NPV-TFC	**-**	**638,137**	**684,767**	**382,733**	**317,632**	**226,798**	**153,428**
					29%	**21%**	**14%**

The cost-benefit analysis of soil compaction, mortar, ash, and bentonite over the next ten years will result a significant farm income. The net present cash flows of treatments were calculated as follows: the first-year cash flow lost due to seepage loss is calculated by taking NPV=$\sum_{t=1}^{n} \frac{R_t}{(1+i)^t} = (153{,}705/(1+0.07)^\wedge 1 = 143{,}650\ ETB$ and farm income loss computation of all ten years was done following the same style. Bentonite gave the highest farm benefits, with a NPV of 317,632 ETB. Ash came in second with a NPV of 226,798 ETB, and cement mortar came in third with a NPV of 153,428 ETB. Using bentonite clay seepage reduction material resulted in a 29% higher NPV, followed by ash, which has a 21% benefit over compaction alone treatment (Table 2). According to Samuel et al., 2017 and 2019, and Mehiret et al., 2019, the crop water requirement of Kulumsa for wheat, potato, and onion crop is 4,255m^3, 5,474m^3, and 4,400m^3, respectively. Consider a farm pond managed by sealant materials, cultivating wheat, potato, and onion crops in 1ha of land to irrigate using 4,255m^3, 5,474 m3, and 4,400m^3 of irrigation amount for one cropping season or annually would bring an additional farm income of about 317,632 ETB with Bentonite and 226,798ETB with Ash compared to the compaction alone treatment (control). Bentonite is more cost-effective than ash and cement mortar and can be tested in areas where water harvesting structures are used for irrigation, particularly if the soil type is similar to that of the study area.

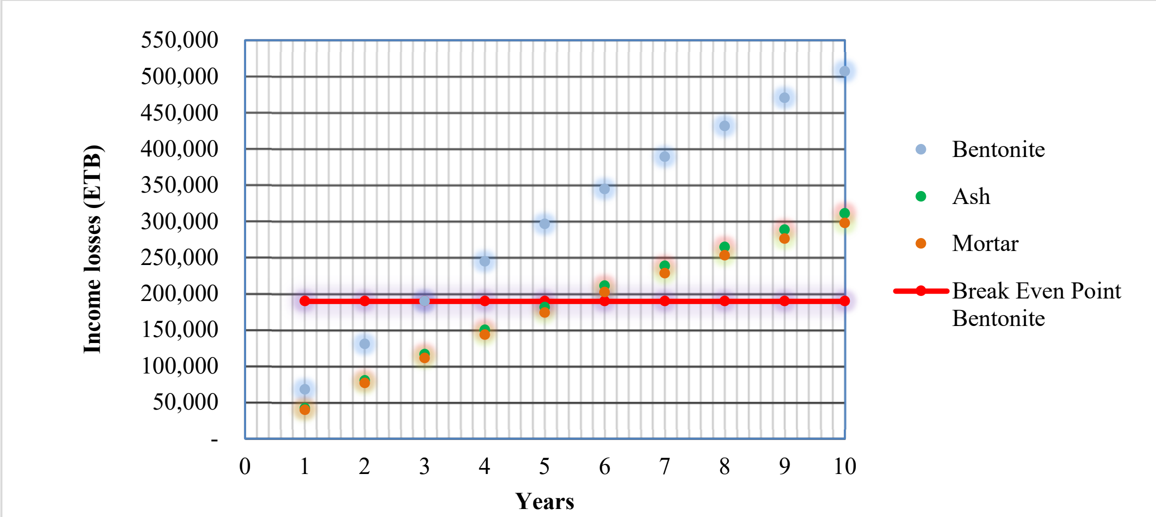

Figure 2: Comparison of sealant materials

Another significant finding of this study was that building a new water harvesting structure and treating it with Bentonite to control water seepage from the water harvesting structure is uneconomical for agricultural purposes in the short term between the third and fourth years. Treating farm ponds with bentonite clay mining material for more than ten years, on the other hand, is profitable, particularly for the production of high-value crops such as potato and onion, which have high water productivity.

According to the analysis results, water harvesting storage treated with Bentonite is financially viable. The maximum cost of seepage controlling materials to cover the bottom surface area of 34*26m^2 water harvesting pond holding a volume of 4,09.69m^3 water used to cultivate (wheat, potato, or onion) for one cropping season under irrigated conditions should not be less than four years to achieve the breakeven point (189,600ETB), which is the point at which the cost of sealant material equals the resulting farm benefits.

CONCLUSION and recommendation

The study was aimed to identify the low cost and efficient sealant material for water harvesting ponds. An extensive cost comparison study between sealant materials were performed considering the seepage reduction and farm income lost. Three seepage controlling materials had tested in term of their financial cost. The cost analysis was assessed in terms of farm income loss considering three crops (Potato, Onion and Wheat) water productivity (kg/m^3), The cost of seepage controlling materials includes the capital cost of material and labor for construction of ponds. The opportunity cost of lost water in seepage from water harvesting pond and the forgone farm benefits. Seasonal or annual lost income from water losses is calculated as the net income in ETB/m^3 times the quantity of lost water seasonally due to seepage losses.

The cost-benefit analysis of soil compaction, mortar, ash, and bentonite over the next ten years resulted a significant farm income. Consider a farm pond managed by seepage reduction material, cultivating wheat, potato, and onion crops in 1ha of land to irrigate using 4,255m^3, 5,474m^3, and 4,400m^3 of crop water requirement or one cropping season or annually would bring an additional farm income of about 317,632ETB with Bentonite by saving irrigation water of 43% and Ash would bring 226,798ETB by saving irrigation water of 23% when compared to the compaction alone treatment (control). Bentonite has the highest farm benefits, with a NPV of 317,632ETB. Ash came in second with a NPV of 226,798ETB, and cement mortar came in third with a NPV of 153,428ETB. Using bentonite clay seepage reduction material resulted in a 29% higher NPV, followed by ash, which has a 21% benefit over compaction alone treatment.

Analysis of cost and income over ten years productivity period showed that, the maximum cost of sealant materials to cover a surface area of 36*26 m^2 and hold 4,709.69 m^3 of water requires at least four years investment period to achieve the breakeven point (189,600 ETB), that corresponds to the point at which the cost of sealant materials equals the resulting farm benefits. Therefore, investing in sealant materials for control seepage lose from water harvesting ponds will have given a profit of their investment after four and above project years.

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