Evaluation of Seepage Losses in Some Selected Local Canal Lining Materials

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ABSTRACT

Seepage rates of some selected local materials for canal lining were evaluated. These materials were: (i) concrete (GC); which comprised of Cement, Sand and Granite of average size of 12mm, in a ratio of 1:2:4. (ii) Termite Mound (TM) (iii) Clay Cement (CLC) (iv) Burnt Cementitious Clay (BCCL) and (v) Clay Soil (CLS). Concrete had the lowest seepage rate, while clay has the lowest. The losses ranged from $0.72 \times 10^{-3} – 1.11 \times 10^{-3}\ m^3\ m^{-2}\ day^{-1}$ for Clay soil lining, $0.82 \times 10^{-3} – 1.05 \times 10^{-3}\ m^3\ m^{-2}\ day^{-1}$ for Termite Mound lining, $0.74 \times 10^{-3} – 0.97 \times 10^{-3}\ m^3\ m^{-2}\ day^{-1}$ for Clay – Cement, $0.69 \times 10^{-3} – 0.85 \times 10^{-3}\ m^3\ m^{-2}\ day^{-1}$ for Burnt Cementitious Clay and $0.68 \times 10^{-3} – 0.83 \times 10^{-3}\ m^3\ m^{-2}\ day^{-1}$ for Concrete lining. It can be concluded that in terms of seepage reduction these materials performed adequately and can be used as canal lining.

Keywords: canal, lining, local material, seepage.

1.0 INTRODUCTION

Losses in irrigation conveyance are majorly due to seepage and evaporation losses. Evaporation is a function of temperature, humidity and wind velocity. This type of loss is practically impossible to prevent, while seepage losses can be prevented by the laying of impervious materials along the channel. Most conventional methods used in preventing seepage losses are the use of compacted clay, tile, soil-cement, concrete, etc. These methods are either too expensive or nor very effective.

25% of seepage losses were reported to take place in small farm ditches [1]. Therefore, to minimize these losses it is expected that farm ditches be lined with suitable materials. Thus, canals are lined wherever feasible in general and to overcome the likely consequences of seepage and conserve precious water resources in a water-scarce area in particular [2]. Therefore, canal lining is most effective in reducing water losses and an appropriate lining should be near impervious, inexpensive, strong and durable.

The merit of a satisfactory lining not only lies in its ability to resist destructive forces of weathering (sun and rain) but it must be resistant to erosion caused by flowing water as well as impermeable enough to reduce seepage losses [3]. Evidence from literature affirmed that irrigation water losses through seepage are enormous. As much as 47% of total amount of water diverted were lost in seepage in India [1]. The study in [1] as reported by [4] revealed that experiments conducted in three minor irrigation projects in Bangladesh showed that as much as 60 % of the total water diverted was lost during conveyance.

Lining is therefore, necessary for controlling seepage losses and also enhance conveyance efficiency. Adequately lined channel will reduce erosion as well as deposition of sediments along the channel bed. Seepage losses from irrigation channels have widely been identified as environmentally critical for the resulting groundwater accessions and associated drainage problems [5]. Seepage, therefore, has a very adverse effect on the surrounding of the canal. It often creates a localized high water table that damages crops in adjacent fields due to water logging and soil salinization.

Many of the conventional materials used in canal lining are either expensive or are not readily available for local farmers. It is therefore, necessary to search for local lining materials that can replace these conventional lining materials with adequate requisite properties that can lead to seepage reduction. Literature search in this area affirmed that more work is needed to achieve adequate data bank on these materials.

The objective of this study was to evaluate the seepage rates of some selected local materials and ascertain their suitability for canal lining.

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2.0 MATERIALS AND METHODS

2.1 Experimental Site

The experiment was carried out at the National Centre for Agricultural Mechanization (NCAM), Ilorin. Ilorin is geographically located in the middle belt of Nigeria with a vegetation of derived savannah, and is situated on a longitude of 4° 30′ E and latitude of 8° 26 N. It receives an average of 1200 mm annual rainfall. The soil of the experimental site is sandy loam and contains 12.48% clay, 18% silt and 69.52% sand. It is classified as Hyplustalf of Eruwa and Odo – Owa series, developed from the parent materials consisting of micaceous schist and gneiss of basement complex which are rich in Ferro-magnesium materials [6].

2.2 Experimental Procedure

2.2.1 *Grain Size Distribution*

Samples of each of the treatments were collected for particle size distribution analysis and texture. The soil samples were air dried and passed through a 2-mm sieve to remove stones and crumbs. The particle size distribution was obtained through sieve analysis of the grains of the samples to determine the sand fraction. The known weight of the samples is allowed to pass through a standard set of sieves and the weight of the fraction retained on each sieve is recorded. These weights were expressed as the percentages of the total weight of the samples. The textural classes of the samples were obtained using the triangular diagram of the USDA as presented by [7].

2.2.2 *Consistency Limits and Hydraulic Conductivity*

The Atterberg limits (plastic and liquid limits) were determined using Cassagrande method. The plasticity index was determined as in Equation 1:

$$PI = W_L - W_P \quad (1)$$

where:

W_L = liquid limit
W_P = plasticity limit
PI = Plasticity Index

The permeability (saturated hydraulic conductivity) of each sample was determined using the constant head permeameter.
The hydraulic conductivity was determined as in Equation 2:

$$K = \frac{QL}{Ah} \quad (2)$$

where:

K = hydraulic conductivity, cm/s
L = Sample length, cm
A = Area of sample, cm^2

The Plasticity Indices and the hydraulic conductivities of the samples are as shown in Table 2.

2.2.3 *Determination of Seepage Losses*

Test ditches of trapezoidal shape were excavated randomly with the following dimensions: bed width: 0.35 m; depth of ditch: 0.40; side slope: 1:2; length of ditch: 2.50 m; top ditch: 1.30 m. The ditches were lined with the treatment materials at 5 cm thickness. Compaction in the ditches were carried out by spreading the materials in three layers and each layer was compacted with a rammer of 4.0 kg attached to an iron handle in layers of 150 mm [8], [9].

The test was done in the dry season when the groundwater table could not contribute to the water levels in the ditches by capillary action. Fig. 1 shows the cross section of the test ditch. The ditches were filled with water to a depth, d_1. The initial depth (d_1) was recorded immediately, while the final depth (d_2) was recorded after 24 hr. The measurements were taken for a period of consecutive days at regular intervals of 24 hours, until the seepage rate became almost constant. The seepage rates were adjusted for evaporation losses from an evaporation pan at the National Centre for Agricultural Mechanization's meteorological station.

The evaporation losses through the pan were determined using the expression by [10] as seen in Equation 3

$$E_o = k_p E_{pan} \quad (3)$$

where:

E_o = evaporation loss, mm
k_p = pan coefficient
E_{pan} = pan evaporation, mm

Evaporation pans have higher rates of evaporation than larger free surface [11] and a factor of about 0.70 is usually recommended for converting the observed rate to those of large surface areas. Therefore, k_p was taken as 0.7. The average evaporation for the impounding days was determined and subtracted from daily seepage losses to give the seepage rate for each day.

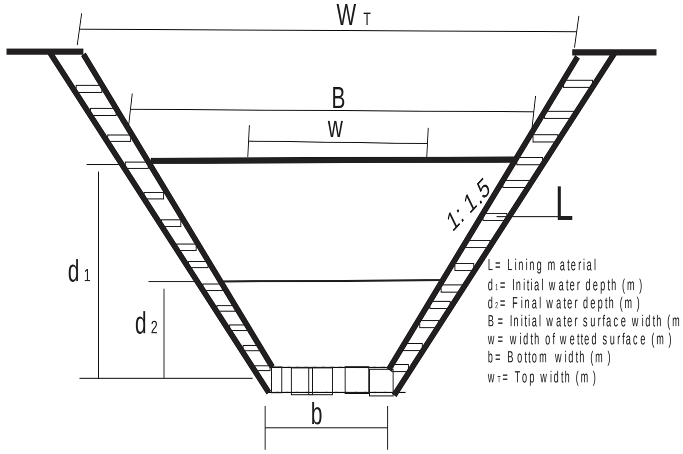

Fig. 1: Ditch Cross Section showing Initial and Final Water Levels

The seepage losses were obtained through the ponding method and were determined by the following formula used by [12]:

$$S = \frac{24\,w(d_1 - d_2)L}{P\,L\,T} \qquad (4)$$

where:

S = seepage rate in m^3/m^2/day
W = average width of water surface (m)
d_1 = Depth of water (m) at the beginning of measurement
d_2 = Depth of water (m) after time T
P = Average wetted perimeter (m)
T = Time interval between d_1 and d_2 (hr), and
L = Length of canal (m)

The wetted perimeter was determined from the geometric dimension of the test ditches in Fig. 1 as follows:

$$P = b + 2\left[\sqrt{\left(\frac{W-b}{2}\right)^2 + (d_1 - d_2)^2}\right] \qquad (5)$$

The parameters in Equation 5 are as defined in Fig1. The graph of the seepage rates for all the treatments is in Fig.2.

3.0 RESULTS AND DISCUSSIONS

3.1 Texture, Consistency limits and Hydraulic Conductivity

From the grain size analysis, it was found that the grain sizes of the five samples were distributed within the following ranges; 6 – 38% silt, 8.48 – 38.43 clay and 43.57 – 82.52% sand.

The liquid limit, plastic limit and plasticity index values representing the soil types were found to be in the range of 34 – 49%, 17 – 24.3% and 19 – 24.7% respectively. The textural classifications of the samples are in Table 1, while the consistency limits, plastic limits and plasticity indices of the samples are in Table 2.

Table 1: Textural and Organic Properties of the Samples

Components (%)	Samples*				
	GC	TM	CLS	BCCL	CLC
Organic Carbon	0.02	0.51	0.24	4.76	2.15
Organic Matter	0.05	0.87	0.67	8.22	3.71
Sand	82.52	59.52	47.52	53.52	43.57
Silt	6.0	30.0	20.0	38.0	18.0
Clay	11.48	10.48	32.48	8.48	38.43

*GC = Concrete; TM = Termite Mound; CLC = Clay-Cement; BCCl = Burnt Cementitious Clay; CLS = Clay Soil

Table 2: Physical and Index Properties of the Samples

Properties	Samples*				
	GC	TM	CLS	BCCL	CLC
Bulk Density (kg/m^3)	1.50	1.49	1.50	1.47	1.57
Dry Density (kg/m^3)	1.45	1.47	1.45	1.43	1.49
Specific Gravity	2.68	2.65	2.60	2.67	2.63
Liquid Limit (%)	34.0	39.0	49.0	41.0	37.0
Plastic Limit (%)	17.0	19.8	24.3	21.5	17.4
Plasticity Index (%)	17.	19.2	24.7	19.5	19.6
Permeability (cm/sec)	8.75×10^{-5}	2.55×10^{-4}	5.63×10^{-5}	1.07×10^{-5}	8.65×10^{-5}

*GC = Concrete; TM = Termite Mound; CLC = Clay-Cement; BCCl = Burnt Cementitious Clay; CLS = Clay Soil

The table shows that the samples have average values of liquid limits and plasticity index. Clay- Cement mixture has the highest plasticity index of 24.7%, while Concrete has the lowest of 17%. Termite mound, Cementitious clay and Clay Soil samples have 19.2%, 19.5% and 19.6% respectively.

The soils are classified into inorganic clays of medium plasticity according to the Cassagrande plasticity chart in the Unified soil Classification System (USCS) according to ASTM standards [13] as employed by [14]. This shows that they are workable and are capable of carrying considerable loads.

Generally, conductivity is affected by the size and distribution of soil particles which generally influence the size of voids conducting flow [15, [16]. The factors that affect hydraulic conductivity are mineral composition, texture, particle size distribution, characteristics of wetting fluid, exchangeable-cation, void ratio and degree of saturation of medium.

A high value of hydraulic conductivity indicates a well-interconnected pore network [17], but contrarily, results from Table 2 show that all the samples have medium permeability and could be good materials for canal lining, if properly managed.

The plasticity indices of the clay-cement and clay soil were highest of the sample which might be due to the higher silt and the lower sand percentage than other samples. It could be observed as in Table 1that generally the clay and silt contents of the samples decreased as the sand content increased. Similarly, increase in plasticity index with an increase in clay content was observed which indicated the workability of the samples due to cohesion between the samples' grain particles; they could be suitable for canal ling. This trend in results was in conformity with the results obtained by [18] and [19].

3.2 Seepage Losses in Channels

Figure 2 shows the rates of seepage losses plotted against time in days elapsed after the commencement of the ponding. The results of seepage studies of the linings with the different lining material showed that seepage losses decreased appreciably with age of lining. At different days, the rates of these losses were reduced to nearly constant values. The losses ranged from 0.72 x 10^{-3} – 1.11 x 10^{-3} m^3 m^{-2} day^{-1} for Clay soil lining, 0.82 x 10^{-3} – 1.05 x 10^{-3} m^3 m^{-2} day^{-1} for Termite Mound lining, 0.74 x 10^{-3} – 0.97 x 10^{-3} m^3 m^{-2} day^{-1} for Clay – Cement, 0.69 x 10^{-3} – 0.85 x 10^{-3} m^3 m^{-2} day^{-1} for Burnt Cementitious Clay and 0.68 x 10^{-3} – 0.83 x 10^{-3} m^3 m^{-2} day^{-1} for Concrete lining.

The lowest seepage loss was obtained on Concrete lining, while the highest was obtained on Clay lining. The magnitude of the losses is of the order: Clay > Termite Mound > Clay Cement > Burnt Clay > Concrete. The losses on Concrete and Burnt Clay lining were gradual, this trend was almost the same on the Clay – Cement lining. The Termite and Clay linings had sudden drops in losses as the days elapsed. The seepage losses were at steady rates after a period of about 7 – 9 days in all the linings.

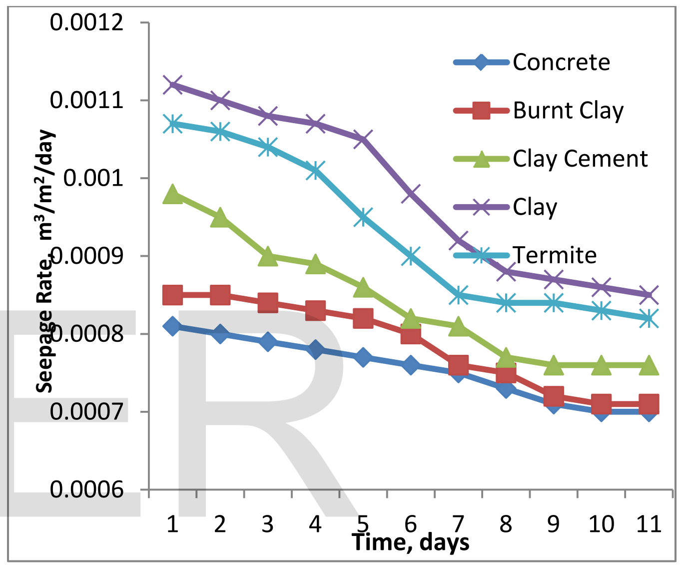

Fig. 2: Seepage rate and Time for the Channels

The results are close to the results obtained by [9] where seepage rate of 2.33 x 10^{-4} m^3 m^2 day^{-1} was obtained for a channel lined with anthill material. Higher seepage rates of 0.037 – 0.125 m^3 m^2 day^{-1} for unlined channel; 0.033 – 0.063 for Clay Soil and 0.045 -0.072 for Clay – Jute linings, respectively were obtained in [1].

4.0 CONCLUSION

These local materials are very promising for utilization in irrigation canal lining in terms of seepage reduction, most especially in small irrigation schemes. It is therefore, concluded that these linings could replace concrete in terms of seepage reduction, though concrete has an edge in terms of durability.

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