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Water Absorption and Erosion Resistance Properties of Soil Blocks Stabilised with *Cissus Populnea* Stem Fibre-Infused Water

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ABSTRACT
The imminent shortage of conventional building materials coupled with environmental concerns due to the manufacturing processes underscore the need for innovative and sustainable solutions. In soil material improvement, research is being shifted into the use of agricultural-based materials for soil stabilisation. It is against this background that, this study investigated the water absorption and erosion resistance of soil blocks stabilised with *Cissus populnea* fibre-infused water. To determine the effect of the *Cissus populnea* fibre-infused content on the soil blocks water absorption and erosion resistance, the infusion concentrations in the mixing water was varied from 0%, 7.5%, 10%, 12.5% and 15% by weight of the water. A total of 75 blocks were produced and tested at 28 days. From the results, the control blocks absorbed 0.47% water while blocks stabilised with 15% *Cissus populnea* fibre-infused water absorbed 0.23% water, representing 51% reduction in the block water absorption. Furthermore, erosion decreased from 5.5mm, 4.5mm, 2.6mm, 0.0mm and 0.0mm for the 0%, 7.5%, 10%, 12.5% and 15% *Cissus populnea* fibre infusion respectively. The study therefore concludes that *Cissus populnea* fibre-infused water, particularly at 12.5% and 15% infusions, positively enhanced the durability of soil blocks, making them suitable for soil housing applications.
Keywords: *Cissus populnea* stem fibre, *Cissus populnea* viscosity, water absorption, density, erosion resistance

1 INTRODUCTION

There is a growing concern of the fast depletion of natural resource materials including conventional building materials. To curb this menace, the United Nations appealed to stakeholders in the construction industry to adopt the usage of sustainable building materials and construction practices that can minimize resource depletion and environmental pollution (United Nations Report, 2015). In support of this appeal, Oyelami and Van (2016) are of the view that exploring innovative applications of local natural resources including lateritic soil materials will offer a significant pathway towards achieving positive change. However, Zami and Lee (2011) reported that the use of soil material in construction has historically presented several setbacks, such as the sensitivity of earth-based buildings to moisture, leading to resultant effects like cracks upon drying, erosion, and structural collapse. Again, Osei-Tutu and Ofori (2009) also indicated that soil building materials strength and durability properties are affected due to their tendency to absorb water readily. To reduce soil material water absorption and erosion to enable it withstand more load in all weather conditions, Olowu, Raheem, Awe and Bamigboye (2014) recommended that it is better to stabilise the soil material with cement or lime. While cement and lime use for soil stabilization may offer significant benefits for soil housing projects, their production processes and escalating prices raise concerns about accessibility, sustainability and environmental impact (Oyelami & Van, 2016). Unlike cement and lime, the processing of agricultural-based materials and wastes do not release greenhouse gases into the environment, making them non-toxic and eco-friendly for soil stabilization (Alam, Ahmad & Malik, 2015).

To reduce the use of cement, lime and other chemical stabilizers, various agricultural plants and residues have been investigated for soil stabilisation. Notable examples include banana stems with sawdust (Ajayi, 2003), maize stalk (Ajayi, 2006), rice husk ash (Alhassan, 2008) and cooked locust bean seed (Akinoso & El-Alawa, 2013). In recent

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studies, Ahirwar and Singh (2020) highlighted the potential of palm leaf as a sustainable and effective soil stabilization material. Its unique properties, including high tensile strength, biodegradability, and cost-effectiveness, make it a valuable resource for construction projects in regions with abundant palm trees. Furthermore, Al-Swaidani, Al-Shaarbaf, Hadi and Al-Saadi (2021) provided compelling evidence for the effectiveness of vetiver grass roots in enhancing the strength properties of soil. Its unique properties, coupled with its sustainability and environmental benefits, make it a valuable resource for various geotechnical applications, including slope stabilization, road construction, and erosion control.

Given the above works, *Cissus populnea* is one of such agricultural-based plant that can potentially be used in many areas including soil stabiliation. It is a strong, woody plant, 8–10m long and 75mm in diameter. According to Soladoye and Chukwuma (2015) *Cissus populnea* plant grows well in tropical Africa, from the coast and stretching through the Savannah zone to the Sahelian woodlands. The plant belongs to the family of Vitaceae/Ampelidaceae and the genus *Cissus*, which comprises of about 350 species. This plant is associated with a myriad of medicinal uses in different parts of the world. Its extracts have been credited with antibacterial properties (Akomolafe, Oboh, Akindahunsi, Akinyemi & Tade, 2013). The root extracts from the plant have been used for the treatment of skin diseases, boils, and infected wounds, as well as for treating urinary tract infections, thus suggesting the plant's antibacterial potency (Nkafamiya, Aliyu & Maina, 2018). The fibre is also used as a binding material and for making paper and baskets (Achikanu & Ani, 2020). Sinchaipanit and Kerr (2019) investigated the impact of *Cissus populnea* mucilage flour on the proximate composition and functional properties, and sedimentation rate of millet kunu, a traditional West African beverage. Nkafamiya, Aliyu and Maina (2018) reported that though *Cissus populnea* has been used for various traditional purposes, its potential in both domestic and industrial applications has not been well-researched scientifically.

In the construction industry, Akinbosoye and Olaoye (2020) studied the potential use of *Cissus populnea* stem fibre as reinforcement for the production of cement fibre board. Even though, Alakali, Irtwannge and Mkavga (2009) reported that *Cissus populnea* is known for its high crude gum (mucilage) composition and is widely used for binding and stabilising purposes, no literature has reported of its potential use as a stabiliser for soil building materials. This study, therefore, assesses the possible use of *Cissus populnea* for soil block stabilization for low-cost rural housing construction. According to Adekanmi, Popoola and Afolabi (2022) soil material plays an important role in the provision of affordable housing units for both rural poor and urban low-income earners in Africa. Furthermore, completely soil-built houses are used to portray cultural diversity for both the rich and poor in Africa. Hence, the findings of this study will benefit both rich and poor in rural and urban communities in Africa who continue to depend on improved soil materials as an integral part in the housing architecture.

2 MATERIALS AND METHODS

2.1 MATERIALS

The following materials were used to produce the soil block samples for the study: soil material, *cissus populnea* stems and water.

2.1.1 Soil Material

The soil material used for this experimental investigation was taken from Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED) in Kumasi, near the Construction Technology Department Laboratory.

2.1.2 *Cissus Populnea*

The *Cissus populnea* stems were obtained from Siriyiri in the Wa West District in the Upper West Region of Ghana. it is a creepy-like plant as shown in Figure 1a. The stems of the plant as shown in Figure 1b were harvested and cut into sizeable lengths of 200 mm as shown in Figure 1c with a hand saw.

a. Plant b. Stems c. Cut pieces of the stems

Figure 1: *Cissus populnea* plant and stems

2.1.3 Water
Clean drinkable tab water conformed to BS EN 1008 (2002) standard specifications, supplied by the Ghana Water Company Limited to the laboratory was used to prepare the soil blocks.

2.2 Methods and Procedures
2.2.1 Cissus Populnea Stem Fibre Preparation
The outer layers of the stems were scrubbed off using a knife and washed in clean water to remove all dirt. The stems were dried and then pounded on a clean, dry surface with a hammer (Figure 2) to obtain sponge-like fibres. To determine the effect of the variation of the *Cissus populnea* fibre infusion on the water absorption and erosion resistance of the soil blocks, the fibre contents soaked in the water were varied from 0%, 7.5%, 10%, 12.5% and 15% by weight of the water, which was kept constant at 8.0kg. The stem fibres were then soaked in the water in four clean transparent plastic containers for a period of 12 hours (Figure 3). The water and the stem fibre mixture were stirred to obtain a uniform mix before the fibres were removed from the water infusion. Samples of the stem fibre-leached water infusions were taken to the engineering laboratory of KNUST and tested for pH and viscosity. The proximate properties and composition of *Cissus populnea* has already been studied and documented (Alakali, Irtwannge & Mkavga, 2009) as presented in Table 1.

Figure 2: Hammering of stems to fibre

Figure 3: Fibres soaked in water

Table 1: Proximate analysis of *Cissus populnea* (Alakali, Irtwannge & Mkavga, 2009)

Parameter	Values in percentage (%)
Moisture	20.10
Protein	4.35
Crude fibre	60.71
Fat	12.31
Ash	12.59
Insoluble ash	0.10

2.2.2 Soil Particle Size Distribution
The particle size distribution of soil has an effect on the compressed soil blocks density. The soil was analyzed for particle size distribution using the sieve analysis test in line with BS 1377-2 (2022). This was done purposely to detrmine the predominant particles size that form the bulk of the soil.

2.2.3 Mix Design
The soil samples and water contents used to prepare the test blocks for all *Cissus populnea* fibre infusion levels were kept constant at 20.0kg and 8.0kg respectively. The BREPAK block press machine (Figure 4) was used to mould the blocks with a constant compaction pressure of 8 MN/m^2. First, 15 number soil blocks were moulded with 20.0kg weight of soil and 8.0kg weight of water without the *Cissus populnea* stem fibre-infused water. These blocks were labelled as control blocks (blocks without cissus populnea fibre-infused water content). Again, 15 number soil blocks were moulded with 20.0kg weight of soil and 8.0kg weight of water containing 7.5% *Cissus populnea* stem fibre-infused water. The mixing and moulding procedure was repeated for water containing 10%, 12.5% and 15% *Cissus populnea* stem fibre-infused water (experimental blocks). In all, a total of 75 number test blocks of size 215 x 105 x 80 mm were moulded for the tests. The blocks were cured in a laboratory environment for 28 days. First, the moulded blocks were covered with polythene sheets for the first seven days to prevent speedy drying which could lead to shrinkage cracks. After seven days, the polythene sheets were removed and the blocks air-dried (Figure 5) for 21 more days before tested.

2.2.4 Test Procedures

The densities of the moulded soil blocks were first evaluated before the water absorption test. Three soil blocks from each stabilization level that have no visible cracks were randomly selected for the density and water absorption tests. All selected blocks were gently cleaned with a non-absorbent cloth to remove any dirt or loose particles on the surface. To ensure accurate measurement, the blocks were further dried in an electric oven (Figure 6) to constant weights. The weight of a block was considered constant when the difference between two weightings was zero. An electric scale (Figure 7) was used to measure the weights of all the test soil blocks. The densities were calculated and the average densities for each stabilization level reported.

BS EN 771-1 (2011) Standard Specifications were followed in the performance of the water absorption by capillary test. The oven-dried constant weighed mass of each block was recorded as M1 and a 5mm depth marked around the base of each block. The blocks were then immersed in water up to the 5mm mark supported by wood stakes (Figure 8) for 10 minutes. After the 10 minutes immersion period, the blocks were removed and weighed again as M2. The difference between the weights before and after the immersion was determined, and the water absorption percentages were calculated using the following equation.

$$Water\ Absorption\ (\%)\ = \frac{M2-M1}{M1} \times 100 \quad (1)$$

Where M1= Mass of block before absorption, M2= Mass of block after absorption

The soil block erosion test was performed using the drip method (Figure 9). The purpose was to determine the rate at which the soil blocks would erode under simulated rainfall conditions. To achieve this, the depths and diameters of the eroded stabilised soil blocks pits were measured using a cylindrical probe in millimetres. The average differences in depth and diameter were then calculated and compared against established standards based on the New Zealand Standard (2022). This allowed for a quantitative evaluation of the erosion resistance of the soil blocks with varying *Cissus populnea* stem fibre-infusions or stabilization levels.

Figure 4: Soil block moulding

Figure 5: Curing blocks by air-drying

Figure 6: Oven-drying of blocks

Figure 7: Weight measurement of blocks

Figure 8: Water absorption of soil blocks by capillary

Figure 9: Simulated erosion test using the drip method

3 RESULTS AND DISCUSSIONS

3.1 Soil Material Particle Size Distribution

The particle size distribution analysis revealed that the soil material used in the experimental study primarily consisted of 51.39% gravel and 37.92% sand. The presence of minimal 0.7% silt and clay indicate a low percentage of fine particles (Figure 10). This characteristic suggests that the laterite soil may be resistant to swelling when exposed to water due to the limited availability of water-absorbing clay minerals. However, the low clay content also implies reduced plasticity and potentially increased permeability, which could impact the workability and water retention capacity of the laterite soil. These findings align with the observations reported by Osuolale, Famakinwa and Olaniyan (2012) in their study on the effect of pH on the geotechnical properties of laterite soil for highway pavement construction.

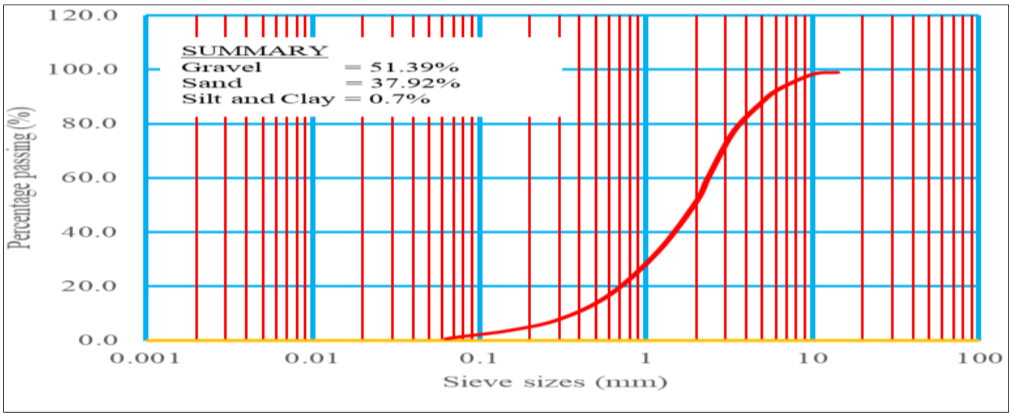

Figure 10: Particle size distribution curve of soil material used

3.2 Cissus Populnea Fibre-infused Water Viscosity and pH

The *Cissus populnea* stem fibre-infused water used in this study exhibited a dark brown colour and a viscosity of 1.3991mm²/s, 1.4016mm²/s, 1.4088mm²/s and 1.4115 mm²/s for the 7.5%, 10%, 12.5% and 15% *Cissus populnea* fibre additions in the water respectively. The pH values range from 6.22, 6.57, 6.81 and 6.90 for the 7.5%, 10%, 12.5% and 15% *Cissus populnea* stem fibre contents in the water respectively. The pH values indicate a slightly acidic but near-neutral nature. This characteristic is crucial for the *Cissus populnea* fibre-infused water suitability as a stabilizer for soil material. Highly acidic or alkaline stabilizers can negatively impact the durability and strength of compressed soil materials. The slightly acidic nature of the *Cissus populnea* stem fibre-infused water may not have potential negative impact on the durability properties of the soil blocks. Water solutions containing high acidic contents usually react with the natural minerals in the soil, particularly clay minerals, leading to the weakening of their bonds. This phenomenon was reported by Osuolale, Famakinwa and Olaniyan (2012), who found that acidic environments negatively affect the geotechnical properties of building soil, including strength and cohesion. Their research attributed this effect to the breakdown of clay mineral structures and the reduced effectiveness of inter-particle bonding mechanisms under acidic conditions.

3.3 Dry Density Test Results

The average densities of the soil blocks studied range from 1846kg/m³, 1863kg/m³, 1912kg/m³, 1927kg/m³ and 1920kg/m³ for water infusions containing 0%, 7.5%, 10%, 12.5% and 15% *Cissus populnea* stem fibre contents respectively (Table 2). From the results, it is observed that density steadily increased with further addition of the *Cissus populnea* stem fibre contents in the water mixture up to the 12.5% infusion level. However, beyond the 12.5% *Cissus populnea* stem fibre content in the water, density declined marginally. The density values obtained in this study are all above the 1000kg/m³ recommended for high density soil bricks (Fadele and Ata, 2018).

Table 2: Density test results (average values, kg/m³)

Curing duration	*Cissus populnea* stem fibre percentage addition in water				
	0%	7.5%	10%	12.5%	15%
28 days	1845.46	1863.08	1911.79	1926.92	1920.45

3.4 Water Absorption

Figure 11 presents the water absorption results for the *Cissus populnea* stem fibre-infused water stabilized soil blocks. As the leached stem fibre content in the water infusion increases, there is a corresponding decrease in water absorption, an observation associated with the viscous and binding nature of the *Cissus populnea* extracts. The control soil blocks recorded a water absorption percentage of 0.47% and this decreased to 0.23% at the 15% *Cissus populnea* stem fibre-infusion content representing 51% reduction in water absorption. This trend aligns with the expectation that a viscous stabilizer would repel water and reduce its ingress into the blocks. In a previous study, Yalley (2018) reported similar decreasing water absorption behaviour of soil bricks stabilized with palm kernel oil residue compared to the control soil brick. The reduction of water absorption with further addition of the palm kernel oil residue in the soil brick was attributed to the nature of the oil residue viscosity. From the laboratory analysis viscosity increased with further addition of the *Cissus populnea* stem fibre in the water infusion. Hence, the *Cissus populnea* stem fibre leached content in the water infusion worked as an effective water repellent, significantly reducing water absorption of the experimental soil blocks with increasing contents compared to the control soil blocks.

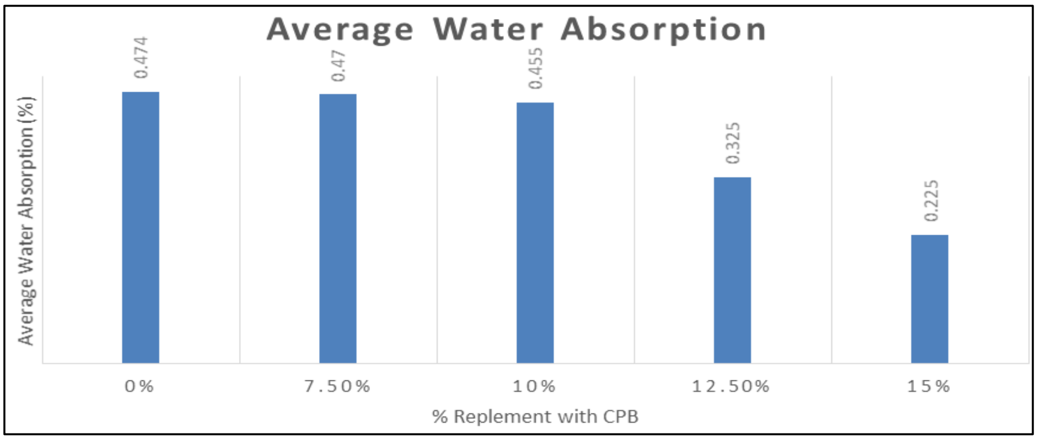

Figure 11: Water Absorption values (%)

4.7 Erosion Test (Drip Method)

Table 3 presents the results of the erodibility index test for the *Cissus populnea* stem fibre-infused water stabilized soil blocks. The depth and diameter of the pits were analysed to determine the erodibility of the blocks based on the New Zealand Standard 4298 (2024) specifications. The findings reveal that 7.5% and 10% *Cissuss populnea* stem fibre-infused water stabilized soil blocks fall within erodibility index values of 4 and 3, respectively, showing very low resistance to wear according to New Zealand Standard 4298 (2024). This indicates that these blocks are susceptible to erosion under moderate to high wear conditions. The 12.5% and 15% *Cissus populnea* stem fibre-infused water stabilized soil blocks demonstrated an erodibility index of 0.0 signifying very high resistance to wear. This result suggests that *Cissus populnea* stem fibre-infused water stabilised soil blocks at higher addition levels possess excellent resistance to erosion and can withstand significant wear and tear. Therefore, water infusions with 12.5% and 15% *Cissus populnea* stem fibre contents exhibited remarkable resistance to erosion, making them suitable for applications where durability and long-term performance are crucial.

Table 3: Average pit depths and diameters (mm)

	% addition of cissus populnea stem fibre				
28 days curing	0	7.5	10	12.5	15
Pit diameter	8.4	7.6	4.10	0.0	0.0
Pit depth	5.5	4.0	3.6	0.0	0.0

4 CONCLUSIONS

This paper investigated the water absorption and erosion resistance of soil blocks stabilized with *Cissus populnea* stem fibre-infused water, and the findings summarized as follows:

i. The *Cissus populnea* fibre content in the mixing water steadily reduced the experimental soil blocks water absorption up to the 15% addition level. The percentage water absorption reduction at the 15% *Cissus populnea* fibre content addition was 51% compared to the control soil blocks.
ii. Again, the soil blocks resistance to erosion were significantly improved. The soil blocks resistance to erosion steadily increased with increasing *Cissus populnea* stem fibre content soaked in the mixing water. The 12.5% and 15% *Cissus populnea* stem fibre content soil blocks recorded zero indent pits and diameters. This implies that the addition of *Cissus populnea* stem fibre in the mixing water up to 12.5% and beyond in the water infusion increased the resistance of the soil blocks against erosion.
iii. From the results, it is evident that *Cissus populnea* content in the mixing water has remarkably enhanced the water absorption and erosion resistance properties of the experimental soil blocks. Hence, *Cissus populnea* stem fibre-infused water stabilised soil blocks could be recommended for use in moderately damp environments where heavy rainfall and wind are common and structural stress is not paramount.

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