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A COMPARATIVE STUDY OF THE IMPACT OF WETNESS OF MAGNETICALLY TREATED SANDY AND LOAMY SOILS ON THEIR TEMPERATURES

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Abstract

This study aimed to compare the effects of magnetically treated sandy and loamy soils on their temperatures when exposed to varying levels of wetness. Governing equations were formed as various assumptions were made representing the condition under which the work was done. The equation was solved and the result graphed. The Hartmann number which represents the magnetic parameter and the thermal conductivities of the soils involved (loam and sand) were examined on the soils' temperature based on the line of this study. Base on the findings, it is concluded that wetness plays an important role in the temperature of magnetic materials. Furthermore, the findings of this study can be used to optimize the treatment of sandy and loamy soils with magnetic materials.

Keywords: *Governing equation, Loamy soil, Magnetic parameter, sandy soil, wetness.*

1.0 INTRODUCTION

The relationship between soil temperature and crop yield has been a topic of great interest in the field of agriculture. Extensive researches have been conducted along this area to understand the impact of soil temperature on plant growth and development. Moreover, thermal properties of these soils are very important and necessary in their use, not only in seed germination, but also in vast areas of engineering, soil science, agronomy, etc.; they influence the microclimate of the soils (Ekwue *et al.,* 2006).

Besides, soil temperature plays a crucial role in determining the yield of crops. The optimal soil temperature range for most crops is between 18 – 24 degrees Celsius. This temperature range promotes efficient seed germination and root development, leading to higher crop yield. Deviation from this optimal range can have significant impacts on crop growth and yield. When soil temperature is too low, it can result in slow seed germination, reduced root growth, and overall stunted plant growth. On the other hand, when the soil temperature is too high, it can lead to the wilting of crops, reduced nutrient uptake and increased susceptibility to diseases and pests. The importance of soil temperature on crop yield cannot be understated. It is crucial to monitor and maintain the optimal soil temperature to ensure maximum crop productivity. By understanding the relationship between soil temperature and crop yield, farmers and researchers can make informed decisions and implement strategies to improve overall crop production. However, in studying the temperature distribution in soils, equations on heat transfer are required, alongside necessary boundary conditions and some important thermal properties of the soil (Gnatowski, 2009).

The thermal conductivity of the soils which is one of crucial soil thermal properties nonetheless ranges from sand to loam to clay to black earth (or humus), in a descending order of value (Edem *et al.*, 2012). In addition, as reported by Anandakumar *et al.,* (2001) sandy-clay soil's thermal conductivity which was initially 0.518W/m K increased to 2.148 W/m K as the moisture content and temperature increased.

Akinpelu *et al.,* (2020) reported that solar radiation and internal heat generally increased sandy-loam and clay-loam soils. However, when the wet basis increases, the level and rate of the increment are more in both soils. They also added that the increment is seen more in sandy-loam than that of clay-loam soil. Some others that study along this line include Ambrollah (2014), who reviewed thermal properties of clay-loam soil. Abu-Hamdeh and Reeder (2000) examined the impacts of thermal conductivity of soil on organic matter, salt concentration, moisture and density. Olaleye *et al.,* (2020) investigated the fluid flow pass sandy soil and how they are being affected by some selected physical parameters.

In the view of above, the present work focuses on making a comparative study of the impact that wetness of magnetically treated sandy and loamy soils has on their temperatures using convective boundary conditions

2.0 MATHEMATICAL ANALYSIS

The equation was formulated considering the flow to be two dimensional of horizontal (y – axis) and vertical (z – axis). Then, making the assumption that the flow is infinite toward the y – axis, reduced the flow to be a function of time (t) and depth (z), being unsteady. The radiation which is from solar source and the internal heat remain constants throughout because of the focus of the study. All other factors except the soils' thermal conductivity, moisture content, and Hartmann number, are as well held constants to be able to clearly scrutinize the parameters of interest. With Boussinesq's approximation, the equations of concern are given as:

Continuity equation

$$\frac{\partial \overline{w}}{\partial \overline{z}} = 0 \tag{1}$$

Energy equation

$$\frac{\partial \overline{T}}{\partial \overline{t}} + \overline{w}\frac{\partial \overline{T}}{\partial \overline{z}} = \frac{k}{\rho C_p}\frac{\partial^2 \overline{T}}{\partial \overline{z}^2} - \frac{1}{\rho C_p}\frac{\partial \overline{q}_r}{\partial \overline{z}} - \frac{1}{\rho C_p}\left(\sigma B_0^2 w_0^2\right)\frac{1}{\rho C_p}Q_0(\overline{T} - \overline{T}_\infty) \tag{2}$$

Subject to:

$$\overline{T}(0,t) = \overline{T}_w + \left(\overline{T}_w - \overline{T}_\infty\right)\left(\eta \cos\left(\frac{\pi \overline{t}}{L}\right)\right) \tag{3}$$

$$\overline{T}(\infty, t) \rightarrow \overline{T}_\infty \tag{4}$$

where,

- $\overline{z}$ = dimensional soil depth
- $\overline{t}$ = dimensional time
- $\overline{w}$ = suction velocity
- $\overline{q}_r$ = heat flux
- C_p = specific heat capacity
- ρ = density
- k = thermal conductivity
- $\overline{T}$,= dimensional temperature
- $\overline{T}_w$ = wall temperature
- $\overline{T}_\infty$ = free stream temperature.

Relevant dimensionless parameters are then introduced as follow:

$$\omega = \frac{w\overline{\omega}}{w_0^2} \qquad \theta = \frac{\overline{T} - \overline{T}_\infty}{\overline{T}_w - \overline{T}_\infty} \qquad t = \frac{\overline{t}}{L} \qquad z = \frac{w_0 \overline{z}}{w} \qquad w = \frac{\overline{t} w_0^2}{t} \tag{5}$$

Suction velocity can either be constant or variable. For practicability of the work, variable suction is employed. This is in line with the work of Nwaigwe (2010):

$$\overline{w} = -w_0(1 + \varepsilon \chi e^{i\overline{\omega}t}) \tag{6}$$

where

- w_0 = initial suction velocity,
- χ = suction parameter and
- ω = frequency of oscillation.

Because the suction is toward the ground's surface, the sign has to be negative. Meanwhile, ε and χ are very small in that $\varepsilon\chi << 1$.

In addition, in the light of the work of Krishna and Reddy (2016), radiative heat flux is specified as:

$$\frac{\partial \overline{q}_r}{\partial \overline{z}} = 4\lambda^2(\overline{T} - \overline{T}_\infty) \tag{7}$$

Where

λ = absorption coefficient.

In a similar way, Akinpelu *et al* (2020) and Kareem & Salawu (2017) presented thermal conductivity as being linear and time dependent:

$$k = k_0(1+\kappa t) \tag{8}$$

Where

κ = variable thermal conductivity parameter,

t = time

k_0 = constant thermal conductivity

Putting equations (5) – (8) into (2),

$$\frac{\partial\theta}{\partial t} - (1+\varepsilon\chi e^{i\omega t})\frac{\partial\theta}{\partial z} = \frac{1}{P_r}\left\{\frac{\partial}{\partial z}\left((1+\kappa t)\frac{\partial\theta}{\partial z}\right)\right\} - R^2 - (Ha)^2 E_c + Q\theta \tag{9}$$

Using equation (5) also on the boundary conditions:

$$\theta(0,t) = 1 + \eta\cos(\pi t) \tag{10}$$

$$\theta(\infty,t) \to 0 \tag{11}$$

where,

$P_r = \dfrac{w\rho C_p}{k_\infty}$ = Prandtl number,

$Ha = (B_0)\left(\sqrt{\dfrac{\sigma}{\rho}}\right)$ = Hartman number

$R^2 = \dfrac{4\alpha^2\theta w}{w_0^2}$ = radiation parameter

$Q = \dfrac{Q_0 w}{\rho C_p w_0^2}$ = internal heat generation parameter

$Ec = \dfrac{w^3}{w_0^2 C_p (T_w^* - T_\infty^*)}$ = Eckert number

3. METHOD OF SOLUTION

The solution to equation (9) would obviously yield an equation for the transient temperature gradient. The equation being a partial differential one and of order two however was first reduced to ordinary differential equation. Perturbation method is deployed to do this with an assumed solution (12) below:

$$\theta(z,t) = \theta_0(z) + \varepsilon e^{i\omega t}\theta_1(z) + o(\varepsilon^2) + \cdots \tag{12}$$

Moreover, neglecting higher order terms $o(\varepsilon)^2$, then using equation (12) alongside its derivatives, by putting them into (9):

$$\theta_0'' + \kappa t\theta_0'' + P_r\theta_0' + P_r Q\theta_0 = P_r R^2 + P_r (Ha)^2 E_c \qquad (13)$$

$$\theta_1'' + \kappa t\theta_1'' + P_r\theta_1' + P_r Q\theta_1 - P_r i\omega\theta_1 = -P_r \chi\theta_0' \qquad (14)$$

The primes connote ordinary differentiation with respect to z.
Boundary conditions which equations (10) – (11) represent, by the assumed solution (12) also become:

$$\theta_0 = 1 + \eta\cos(\pi t), \qquad \theta_1 = 0 \qquad \text{at} \qquad z = 0 \qquad (15)$$

$$\theta_0 \to 0, \qquad \theta_1 \to 0 \qquad \text{as} \qquad z \to \infty \qquad (16)$$

The emerged ambient temperature distribution which is the analytical solution to equations (13) and (14), taking boundary conditions (15) and (16) into consideration then become:

$$\theta = W_1 + W_2 \qquad (17)$$

where,

$$W_1 = C_1 e^{m_1 z} + C_2 e^{m_2 z} + C_3$$

$$W_2 = \varepsilon e^{i\omega t}\left(C_4 e^{m_3 z} + C_5 e^{m_4 z} + C_6 e^{m_1 z} + C_7 e^{m_2 z}\right)$$

$$m_1 = -\frac{P_r}{2(1+\kappa t)} + \sqrt{\frac{P_r^2}{4(1+\kappa t)^2} - \frac{P_r Q}{1+\kappa t}}$$

$$m_2 = -\left(\frac{P_r}{2(1+\kappa t)} + \sqrt{\frac{P_r^2}{4(1+\kappa t)^2} - \frac{P_r Q}{1+\kappa t}}\right)$$

$$m_3 = -\frac{P_r}{2(1+\kappa t)} + \sqrt{\frac{P_r^2}{4(1+\kappa t)^2} + \frac{P_r (i\omega - Q)}{1+\kappa t}}$$

$$m_4 = -\left(\frac{P_r}{2(1+\kappa t)} + \sqrt{\frac{P_r^2}{4(1+\kappa t)^2} + \frac{P_r (i\omega - Q)}{1+\kappa t}}\right)$$

$$C_1 = -C_3 e^{-m_1 z}$$

$$C_2 = 1 + \eta\cos(\pi t) + C_3\left(e^{-m_1 z} - 1\right)$$

$$C_3 = \frac{R^2 + (Ha)^2 Ec}{Q}$$

$$C_4 = \frac{-C_6 e^{m_1 z}}{e^{m_3 z}}$$

$$C_5 = -(C_4 + C_6 + C_7)$$

$$C_6 = \frac{-P_r \chi m_1 C_1}{(1+\kappa t)m_1^2 + P_r m_1 + P_r Q - P_r i\omega}$$

$$C_7 = \frac{-P_r \chi m_2 C_2}{(1+\kappa t)m_2^2 + P_r m_2 + P_r Q - P_r i\omega}$$

4.0 RESULTS AND DISCUSSION

For more applicability of our results and easy discussion of it, using an idea of an experimental set up, two samples of sandy soil and two samples of loamy soil are supposed to be collected from a location. Each sample then separated into two parts, one part being magnetically treated and the other being left untreated as a control. Each part was then exposed to different levels of wetness (moist and wet) and their temperatures were measured.

Following that line of thought, a model above (equation 2) alongside the boundary conditions (equations 3 and 4) was developed to suit the work. This was done using some heat transfer equations with relevant assumptions which suggest the conditions at which the experiment was carried out.

The equation (17) that represents the ambient temperature of the soil was then subjected to different tests. This was carried out by examining numerical values of the thermo-physical properties of these soils on the equation. Mat lab R2009b software was afterward employed with these numerical values to draw the graphs for proper assessments.

Table 1 (below) presents the thermo physical properties of the soils used in the work.

Similarly, in line with some other existing literatures like Mohammed (2010), some numerical values for the physical parameters involved in the work are presented on table 2. These values are valid throughout the work except/otherwise stated.

Table 1: Sandy and Loam soils Thermo-physical property (Abu-Hamdeh and Reeder, 2000)

Soil	Thermal Conductivity (W/m K)	Moisture Content (%)
Loam	0.29	1.4 (moist)
Sand	0.58	1.4 (moist)
Loam	0.76	21.2 (wet)
Sand	1.94	21.2 (wet)

Table 2: Numerical values of parameters involved

P_r	R	Q	Ha	Ec	t	η	ω	ε	χ
0.71	0.10	0.01	1.00	0.01	0.1	1.0	$\pi/2$	0.01	0.5

Figure 1 and 2 simply present the effects of an increasing Hartmann number (magnetization) on the temperature of loamy and sandy soils respectively. It is obviously discovered that the rising magnetic field boost the temperature of both soils.

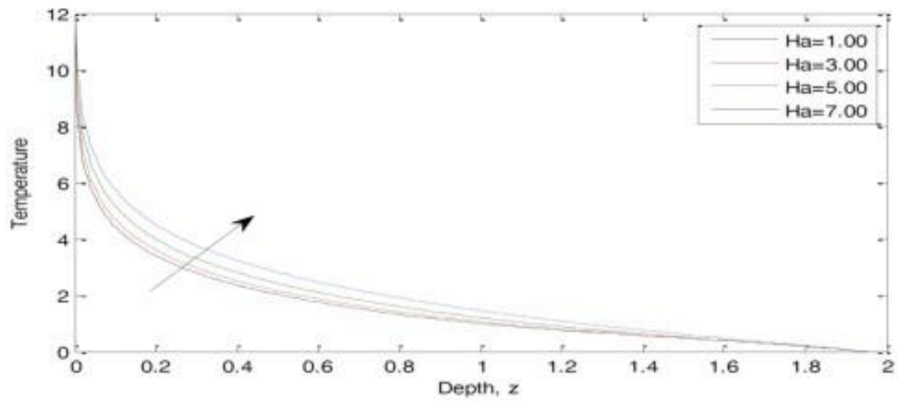

Figure 1: Effects on increasing magnetization on loamy soil's temperature.

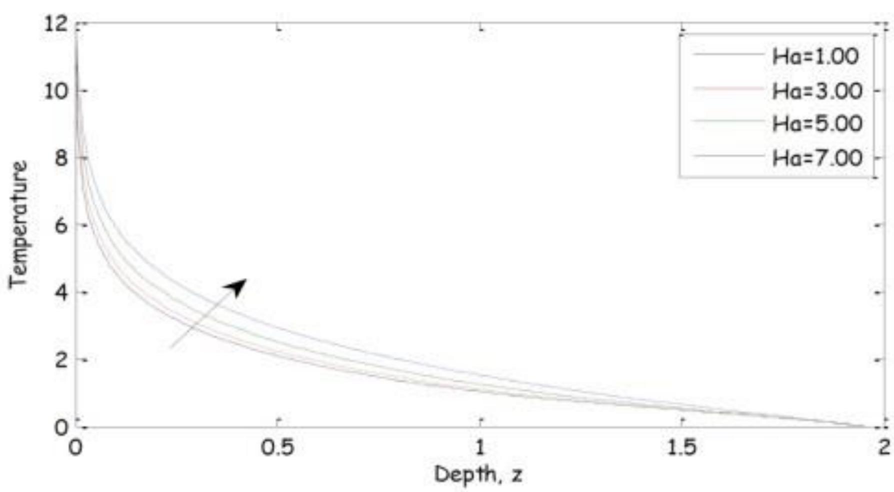

Figure 2: Effects on increasing magnetization on sandy soil's temperature.

In figure 3 and 4 which depict the impact that wetness has on loam and sand, when wetness increased in percentage, the temperature of both soils increased as well.

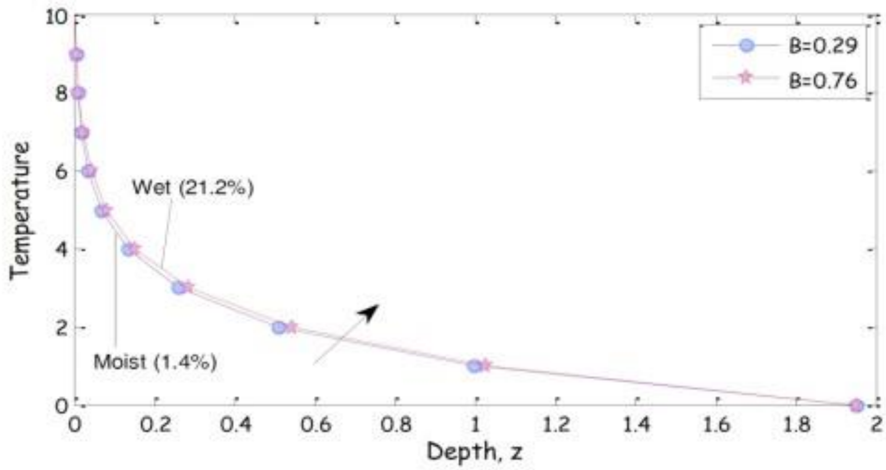

Figure 3: Effects on increasing wetness on loamy soil's temperature.

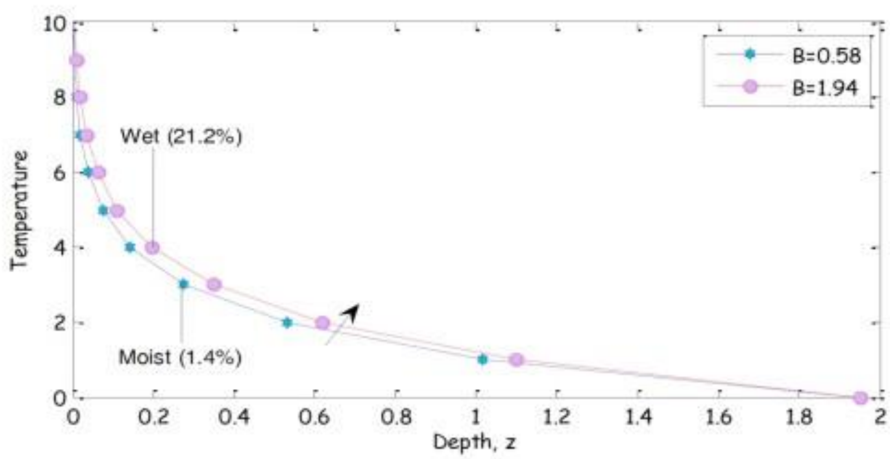

Figure 4: Effects on increasing wetness on sandy soil's temperature.

Figure 5 and 6 however image the impact that wetness has on magnetically treated and untreated loamy and sandy soils respectively. When the soil water content increased from moist (1.4%) to wet (21.2%), the temperature of the soils increases. Moreover, as the soils are being treated magnetically, the increments become more obvious.

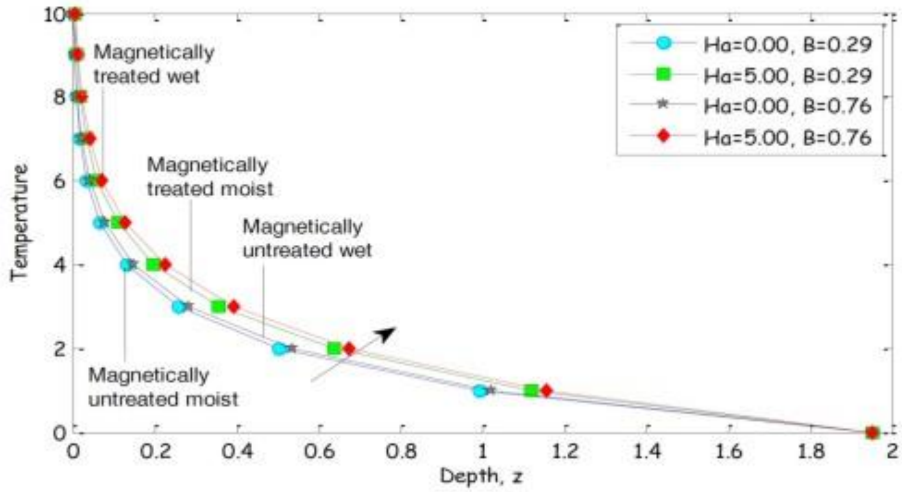

Figure 5: Effects of wetness on magnetically treated and untreated loamy soil's temperature.

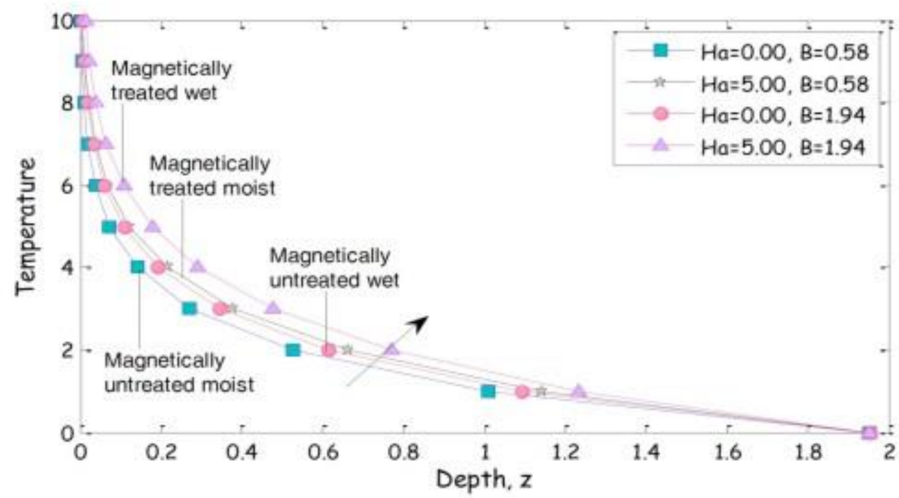

Figure 6: Effects of wetness on magnetically treated and untreated sandy soil's temperature.

In figures 7 and 8, comparative study was made on how wetness affects the magnetically untreated and treated sandy and loamy soils. In both cases, the level of water content affects the temperature of both soils. However, the increasing temperature as a result of the increasing moisture content is more obvious in sandy soil than in loam.

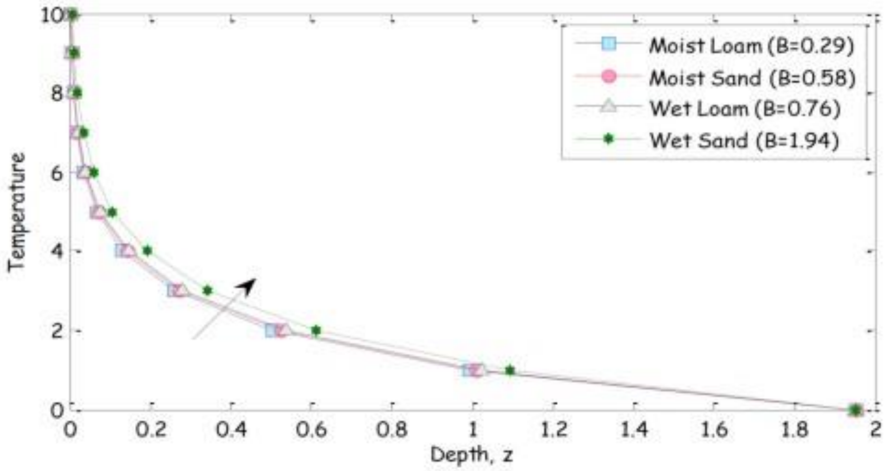

Figure 7: Comparing effects of wetness on magnetically untreated Loamy and sandy soils' temperature.

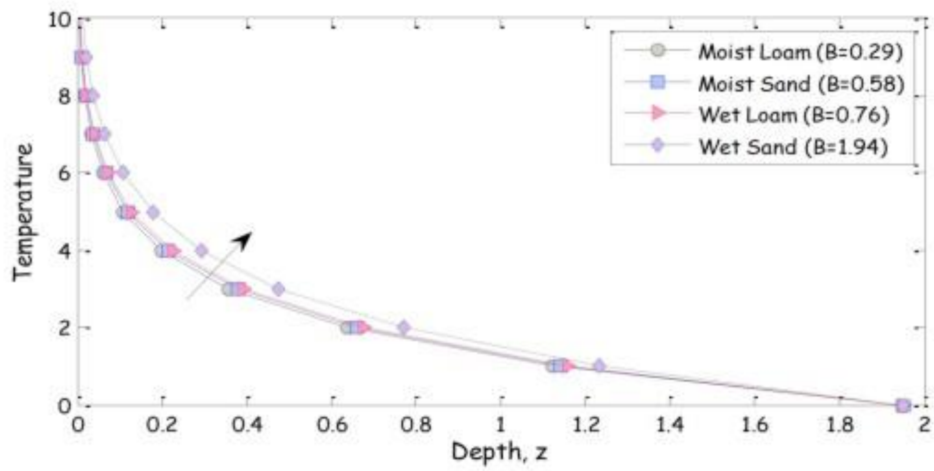

Figure 8: Comparing effects of wetness on magnetically treated Loamy and sandy soils' temperature.

5.0 CONCLUSION

A comparative study of the impact of wetness of magnetically treated sandy and loamy soils on their temperatures was done and a model developed.

The results indicated that, overall, the magnetically treated soils experienced higher temperatures than untreated soils, especially under more wet conditions. Additionally, the sandy soils experienced higher temperatures than the loamy soils across all conditions. These suggest that magnetically treated soils may be more effective than untreated soils at moderating the temperature of the local environment.

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