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Prediction of Temperature Gradient and Soil Water Content through a Sandy Clayey Soil by TEMP/W Simulations

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Abstract
In the present research work the combined effect of temperature gradient and water-content on soil water movement through the sandy clayey soil has been computed by using the slave program of Geo-Slope software i.e. SEEP/W and TEMP/W respectively. The 2-D mesh was developed using TEMP/W which was 25 m long and 14 m in depth and having 390 nodes and 350 elements respectively. The soil region was assumed to be a sandy clayey soil with bulk density 1.55 gm/cm^3 and saturated hydraulic conductivity (Ks) (1.77 x 10^{-6} m/s) accordingly. The initial atmospheric and soil temperature was kept at 45°C and 20°C respectively. The irrigation of 1 inch water was applied on the surface of the land and the time step sequence consists of 35 steps. The simulation results revealed that after infiltration process the temperature at the soil surface started rising due to low water content the volumetric heat capacity of soil became smaller and therefore maximum heat rose. While at all other depths there was an abrupt increase in temperature for the first 5 days. However, after 15 to 20 days temperature became somewhat constant at depth 30 inch till depth 48 inch. Furthermore, at 6 inch depth, a sharp transition was occurred from 1st day to 15th day in which water content decreased from 0.286 m^3 water / m^3 to 0.261 m^3 water / m^3 because of pore space available for air intrusion resulting in higher evaporation potential. After 20th day the water content at 6 inch depth was found unchanged for the rest of the period. However, due to higher evaporation from the open water surface and downward temperature gradient, at soil depths i.e. 12, 18, and 24 inches the water content decreased gradually and became constant after 20 to 25 days. For the remaining soil depths the water content remained at the equilibrium state.
Keywords: Finite Element Modeling, Temperature Gradient, Water Content, SEEP/W, TEMP/W, Geo-Slope.

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INTRODUCTION

Soil acts as a sponge to take up and retain water. Movement of water into soil is called infiltration, and the downward movement of water within the soil is called percolation, permeability or hydraulic conductivity. Pore space in soil is the conduit that allows water to infiltrate and percolate (Marco *et al.,* 2008). It also serves as the storage compartment for water. Movement of water in the soil is dependent upon the size, number and continuity of the soil pores. Water movement through fine-textured soil into underlying sand and gravel does not occur until the finer material above the gravel is fully saturated (Carter *et al.,* 2000). Because the smaller pores, in the finer material on the upper layer, have a greater attraction for the water than the relatively larger pores on the underlying layer, the water moves laterally and fills the upper layer before moving into the coarse material below. After the upper layer becomes saturated, water enters the underlying layer (Arshad *et al.,* 2016).

The unsaturated zone plays a significant role in the hydrological cycle as it forms a link between surface runoff, evapotranspiration, and groundwater recharge. Simultaneously it controls the conversion of incoming solar radiation and atmospheric radiation into sensible heat and evaporative heat losses (Newman et al., 1997). The water and energy balances are linked at the earth atmosphere interface through evaporation by which most of the precipitation received by the earth is returned back to the atmosphere. Beneath the soil surface, water and temperature gradients may induce moisture flow. The germination of seeds and the subsequent growth of roots strongly depend on both the water-content and temperature profiles in the upper soil layer (Morgenstern, 2000).

Nowadays, many computer softwares have come in general use, and any hard computations and simulation can be carried out through them by giving appropriate inputs and data (Arshad *et al.,* 2015). This results in less error frequency and more detailed analysis when compared with field observations. In order to simulate the combined effect of water-content and temperature gradients on soil water movement there are many numerical solution methods i.e. Finite Differences (FDM), Finite Elements (FEM) and Boundary Elements (BEM) (Geo-Slope, 2007). But the FEM is an effective numerical technique because of its numerous applied fields such as groundwater flow, multiphase flow, and mass flow through pours medium (Arshad *et al.,* 2014). By keeping the above facts in view the present research study was conducted to predict the combined effect of temperature gradients and soil water-content on soil water movement through the sandy clayey soil by using slave program of Geo-Slope software i.e. TEMP/W for the development of numerical model and its analysis.

MATERIALS AND METHODS

Steps for Modeling

In order to develop a numerical model, slave program of Geo-Slope Software i.e. (TEMP/W) for the temperature and water content profile analysis was used. In first attempt by using TEMP/W finite element mesh was generated (Arshad, 2013). The mesh is assumed to be 25 m long and 14 m in depth. According to the given conditions the entry and exit location are assigned as a boundary conditions for the mesh. Then geological parameters and material properties are calibrated through (SEEP/W) accordingly (Arshad *et al.,* 2017). After the development of complete model, it is then verified by the TEMP/W software. The initial atmospheric and soil temperature was kept at 45°C and 20°C respectively (Newman *et al.,* 2000). The irrigation of 1 inch water was applied on the surface of the land. The time step sequence consists of 35 steps. Time starts by Zero day ends by 40 days respectively. Finally, it is then verified by TEMP/W and computation of different parameters for different soil depths i.e. 6, 12, 18, 24, 30, 36, 42, and 48 inches through the soil profile is carried out accordingly.

RESULTS AND DISCUSSION

FEM Mesh Formation and Its Verification

The FEM mesh was composed of rectangular type of elements of 1 m size (Figure 1). The domain was discretized into a mesh by 390 nodes and 350 elements (Arshad *et al.,* 2014). The material properties for the 2-D mesh with proper dimensions were made as input to the software respectively and verification has been made accordingly. It was assumed that the complete soil region composed of sandy clayey soil with bulk density 1.55 gm/cm^3 and saturated hydraulic conductivity (Ks) (1.77 x 10^{-6} m/s) accordingly (Arshad, 2015). After all the necessary inputs, the computer program TEMP/W verified the mesh development and delivered report that the vertical and horizontal meshing was strong enough and there was no error in formation of mesh model. Thus the model was ready for computation and analysis of the results.

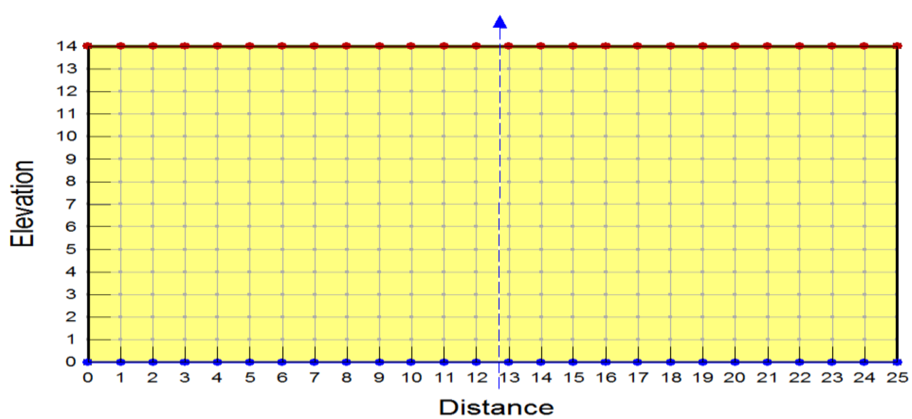

Fig. 1. The mesh of the domain showing the boundary conditions for TEMP/W analysis

Analysis of Water Movement through Soil Profile by TEMP/W

Temperature Profile

Through TEMP/W simulations results it has been observed that after the infiltration process the temperature at the soil surface started rising immediately till 5th day and gradually increases in between 5 to 10 days respectively. The simulation results also showed that the temperature profile for all the depths are of same pattern and the soil temperature decreases with the depth (Adey *et al.,* 2012). Figure 2.a – 2.h described the contours of different temperature changes among the different soil depths at different interval of time obtained by TEMP/W simulations (Table 1).

Table 1. Computed Temperature Gradient vs Time for different depths

Time	Temperature ^{o}C							
(Days)	Depth 6 inch	Depth 12 inch	Depth 18 inch	Depth 24 Inch	Depth 30 Inch	Depth 36 Inch	Depth 42 Inch	Depth 48 inch
0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
5	40.1	38.0	36.8	36.1	34.0	32.1	29.2	26.1
10	43.4	40.9	39.6	38.7	36.6	34.4	31.4	28.0
15	46.9	44.7	43.2	42.3	40	37.6	34.3	30.6
20	46.1	43.7	42.3	41.4	39.1	36.8	33.6	29.9
25	44.8	42.8	41.4	40.5	38.3	35.2	32.9	29.3
30	48.0	45.6	44.2	43.2	37.2	34.9	33.1	28.2
35	47.2	44.7	43.9	42.3	38.1	33.2	32.1	28.1
40	49.1	45.0	43.7	42.1	37.6	33.4	32.6	27.9

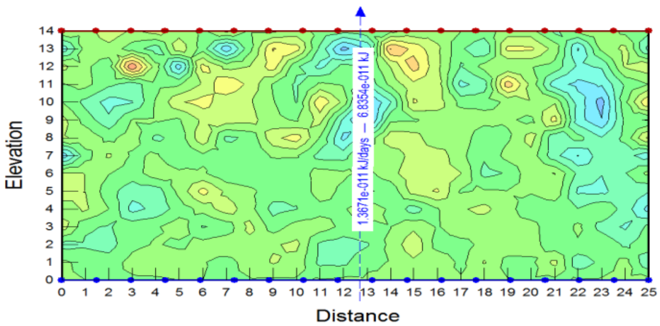

Fig. 2 (a). Temperature Gradient analysis at 05 days.

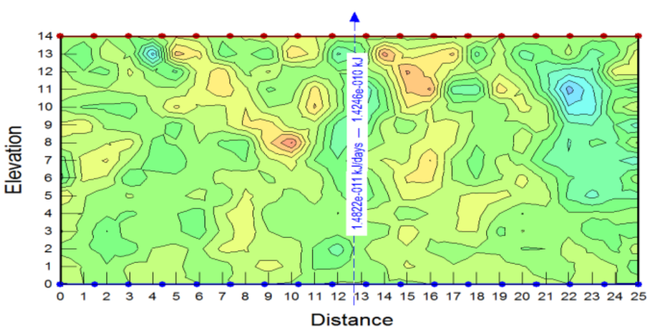

Fig. 2 (b). Temperature Gradient analysis at 10 days.

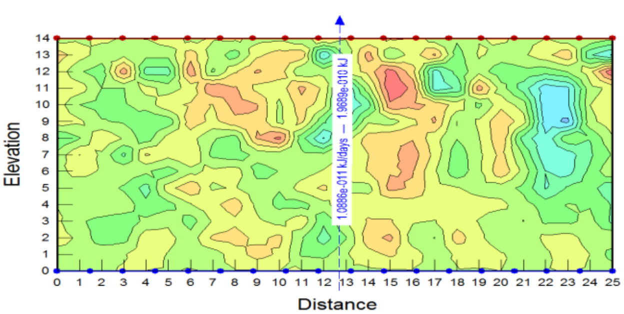

Fig. 2 (c). Temperature Gradient analysis at 15 days.

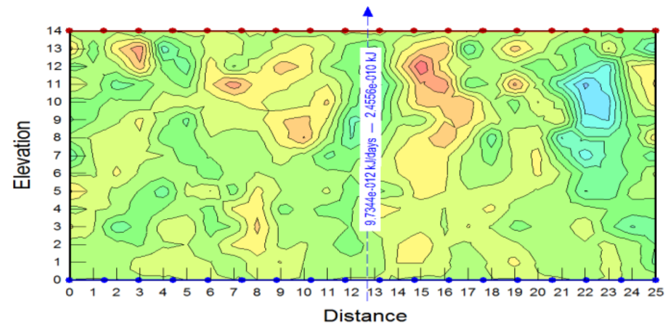

Fig. 2 (d). Temperature Gradient analysis at 20 days.

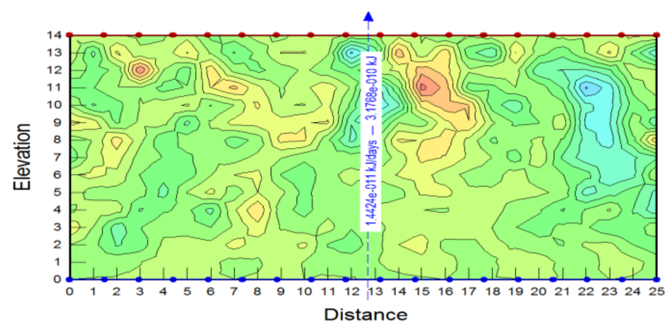

Fig. 2 (e). Temperature Gradient analysis at 25 days.

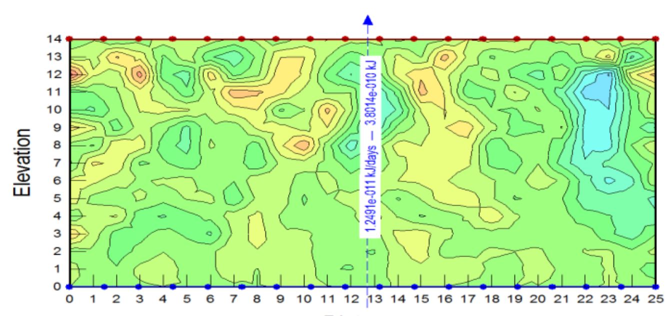

Fig. 2 (f). Temperature Gradient analysis at 30 days.

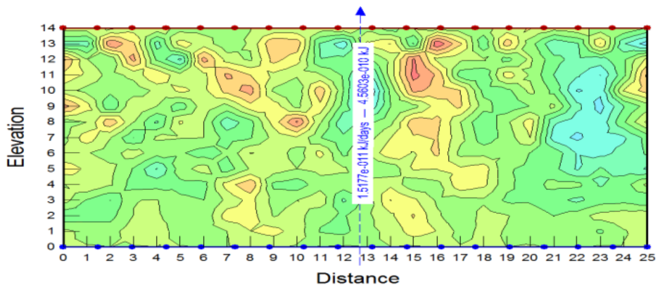

Fig. 2 (g). Temperature Gradient analysis at 35 days.

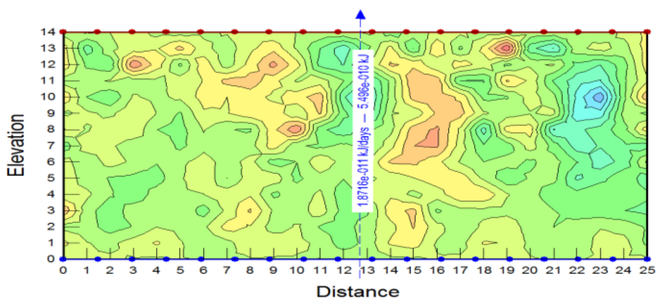

Fig. 2 (h). Temperature Gradient analysis at 40 days.

The continued rise in temperature at the soil surface was due to the reduction in water content, this is because at low water contents the volumetric heat capacity of soil becomes smaller. From the temperature profile it has also been noticed that the heat radiation considerably affects the temperature gradient just below the soil surface, due to which less energy was transferred down the soil profile and smaller proportion of the heat radiation was used to evaporate water. However, maximum heat raised the temperature of the soil surface.

At all depths there was an abrupt increase in temperature for the first five days. However, after 15 to 20 days temperature becomes somewhat constant at depth 30 inch till depth 48 inch accordingly (Figure 3). These results are according to the findings of (Arif, 2009), who concluded that the rise of temperature at the soil surface will continue till the column attained a quasi-steady-state condition. However, at the other depths, temperature rose gradually until 10 days and then became almost constant.

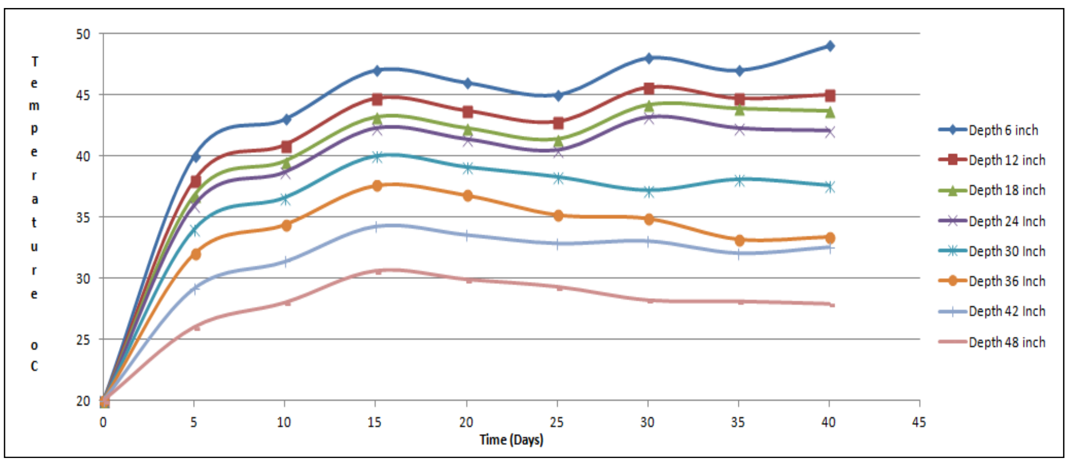

Fig. 3. Computed Temperature Gradient vs Time for different depths

Water-Content Profile (θ)

The predicted results obtained from TEMP/W program showed that at 6 inch depth, a sharp transition occurred from 1st day to 15th day in which water content decreased from 0.286 m^3 water / m^3 to 0.261 m^3 water / m^3 (Table 2). After 15th day till 20th day the water content at 6 inch depth decreased drastically from 0.261 m^3 water / m^3 to 0.109 m^3 water / m^3 and after that remained unchanged for the rest of the period. This is due to the pore space was available for air intrusion and due to which potential evaporation was higher. However, at soil depths i.e. 12, 18, and 24 inches the water content decreased gradually and becomes constant after 20 to 25 days.

This is because the evaporation from the open water surface found high and the temperature gradient was also downward (Figure 4). For the remaining soil depths the water content remained almost at the equilibrium state. This is practically due to the formation of dry layer at the soil surface and due to the replenishment of the water from the water table. Similar results were obtained by (Vishnoi *et al.,* 2011), who observed that as the water evaporates only from the top few cm of the soil, the surface dried rapidly. The rapid drying of the soil surface disrupted the liquid continuity in the pores of the transmission zone below it, thus restricting the upward liquid movement from deeper soil layers and the water movement could occur only in the vapour phase.

Table 2. Computed Water Content vs Time for different depths

Time (Days)	Water Content (θ) (m^3 water/m^3)							
	Depth 6 inch	Depth 12 inch	Depth 18 inch	Depth 24 Inch	Depth 30 Inch	Depth 36 Inch	Depth 42 Inch	Depth 48 inch
0	0.286	0.291	0.312	0.317	0.321	0.367	0.415	0.517
5	0.280	0.285	0.302	0.309	0.321	0.367	0.415	0.517
10	0.272	0.279	0.281	0.290	0.321	0.367	0.415	0.517
15	0.261	0.268	0.279	0.284	0.321	0.367	0.415	0.517
20	0.109	0.268	0.274	0.278	0.321	0.367	0.415	0.517
25	0.109	0.249	0.264	0.271	0.321	0.367	0.415	0.517
30	0.109	0.228	0.251	0.265	0.321	0.367	0.415	0.517
35	0.109	0.228	0.251	0.263	0.321	0.367	0.415	0.517
40	0.109	0.228	0.251	0.263	0.321	0.367	0.415	0.517
45	0.109	0.228	0.251	0.263	0.321	0.367	0.415	0.517

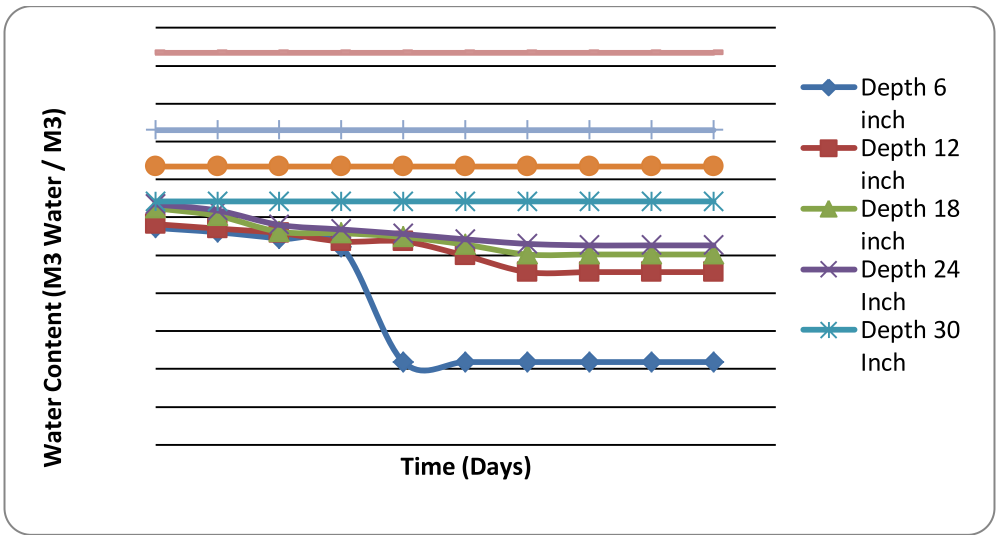

Fig. 4. Computed Water Content (θ) vs Time for different depths

CONCLUSION

In the present research work using Geo-Slope software, the combined effect of temperature gradients and soil water-content on soil water movement through the sandy clayey soil was studied. SEEP/W software was used to compute subsurface flow of water through the developed mesh, while TEMP/W for the development of numerical model and its analysis respectively. The overall results of the study showed that after infiltration process the temperature at the soil surface was started rising due to the reduction in water content this is because at low water contents the volumetric heat capacity of soil becomes smaller; therefore, maximum heat raised at the soil surface. While at all other depths there was an abrupt increase in temperature for the first five days. However, after 15 to 20 days temperature becomes somewhat constant at depth 30 inch till depth 48 inch.

Furthermore, at 6 inch depth, a sharp transition was occurred from 1^{st} day to 15^{th} day in which water content decreased from 0.286 m^3 water / m^3 to 0.261 m^3 water / m^3. This is because of pore space was available for air intrusion and due to which potential evaporation was higher. After 20^{th} day the water content at 6 inch depth was found unchanged for the rest of the period. However, at soil depths i.e. 12, 18, and 24 inches the water content decreased gradually and becomes constant after 20 to 25 days. This is due to the evaporation from the open water surface found high and the temperature gradient was also downward. For the remaining soil depths the water content was remained at the equilibrium state. Hence, it can be concluded that TEMP/W is capable of predicting the temperature gradient and water content. Furthermore, TEMP/W can be used for analyzing thermal changes in the ground due to environmental factors as its comprehensive formulation makes it possible to analyze both simple and highly complex geothermal problems.

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CONFLICT OF INTEREST

The authors declare that they don't have any conflicts of interest and are also not interested in competing with anyone.

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