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EFFECT OF MOISTURE AND BULK DENSITY ON SOIL TEMPERATURE.

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ABSTRACT

The effects of moisture and bulk density on soil temperature have been studied on loamy sand. The study revealed that as soil moisture increased from air-dry state, maximum soil temperature decreased to a minimum at the hygroscopic point, however, maximum soil temperature increased with increasing soil moisture. Bulk density is used to represent the compactness. It was discovered that maximum soil temperature increased with increasing bulk density.

Keywords: Moisture content, Bulk density, Soil temperature, Thermal diffusivity, Thermal conductivity.

INTRODUCTION

The role of moisture and bulk density on variations of important soil phenomena such as pore water pressure, soil thermal diffusivity etc. have been widely studied (Larson and Gupta, 1980; Harred and Saeed, 1980; Lal, 1981). Larson and Gupta (1980) reported that, during compression of unsaturated agricultural soils, the pore water pressure decreases to a minimum, and then increases as the applied mechanical stress increases. They explained that, the degree of water saturation at which minimum pore water pressure occurs, appears to be constant for a given soil (but increases to some extent with the clay content of the soil). Soil bulk density and the distotional strains associated with most of its processes is a major concern of heavily mechanized agriculture (Peterson, 1994). Effects of water content, temperature and solute concentration in transport phenomena in soil are hard to predict without a model (Noborio et al, 1996). According to Harred and Saeed (1980), the movement of elements, such as phosphorus, through the soil to plant roots is primarily by the process of diffusion; and the rate of diffusion coefficient D, is influenced by the amount of moisture in the soil, where

$$D = Ae^{-a\psi} + B$$

A, a, B are constants and ψ is the surface tension of water in the soil. Besides, soil moisture and bulk density have relationship with soil physical properties - structure, texture etc. which affect porosity and the inherent ability of a soil to be well aerated. Plant growth rates may be reduced if soils become saturated with water, causing a reduction in oxygen diffusion rates (Sikes and Pettit, 1980). This is because the rate of gaseous diffusion through a soil is dependent upon the fraction of the pore space occupied by water.

Soil temperature is important in determining the rate of biological processes, and as a result, it has a great influence on the sources and sinks for gases in the soil. Plant processes such as germination, photosynthesis and transpiration are soil temperature dependent. Germination of crops requires an optimum soil temperature and is

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consequently inhibited at any other soil temperature (Kirkham and Powers, 1972; Sikes and Pettit, 1980). The role of soil temperature on the rate of most chemical reactions that release nutrients to plants can not be over emphasized, while Shuman (1980) noted that varying temperature and moisture cause significant changes in the extractability of most microelements (manganese, iron, copper and Zinc). Similarly microbial activities in the soil are influenced significantly by soil temperature, and at (extremely) high soil temperatures the micro-organisms are destroyed.

The propagation of heat in the soil to plant roots depends on the mean soil temperature gradient, where T is soil tempereture

$$\frac{\Delta T}{\Delta Z} \dots\dots\dots\dots\dots\dots 1$$

and thermal conductivity k, of the soil; hence the heat flow rate (source strength) Q is given by

$$Q = -k\frac{\Delta T}{\Delta Z}\cdot\frac{q}{\rho c} \dots\dots\dots\dots\dots\dots 2$$

where Z is the depth of soil temperature penetration, ρC is the volumetric heat capacity (ρ and C are density and specific heat capacity of the soil respectively) and q is the quantity of heat liberated per unit length of the heating source (Bristow et al; 1994). The vertical changes of Q lead to the warming or cooling of the soil. The actual temperature change resulting from these processes depends not only on the amount of energy added or subtracted, but also upon volumetric heat capacity ρC.
(Oke, 1978). According to Bristow et al the temperature distribution is expressed as

$$T(Z, t) = \frac{Q}{4\pi\sigma}\exp\left(\frac{-Z^2}{4\sigma t}\right) \dots\dots\dots\dots\dots\dots 3$$

where T is the temperature, t is the time σ is the thermal diffusivity of the soil; and Bristow et al have reported that by taking the derivative of eqn (3) - with respect to time and equating it to zero, one could obtain formulae for the determination of both thermal diffusivity σ and volumetric heat capacity ρc as follows

$$\sigma = \frac{Z^2}{4t_m} \dots\dots\dots\dots\dots\dots 4$$

and

$$\rho C = \frac{q}{e\pi Z^2\Delta T_m} \dots\dots\dots\dots\dots\dots 5$$

Here t_m is the time at which the maximum temperature change ΔT_m is recorded at distance Z from the heat source and e is exponential term in eqn (3).
Hence, the total thermal response of the soil is directly proportional to its thermal conductivity and volumetric heat capacity; this is expressed as

$$k = \sigma\rho C \dots\dots\dots\dots\dots\dots 6$$

Where thermal diffusivity σ is a measure of the time required for soil temperature changes to travel within a column of the soil.

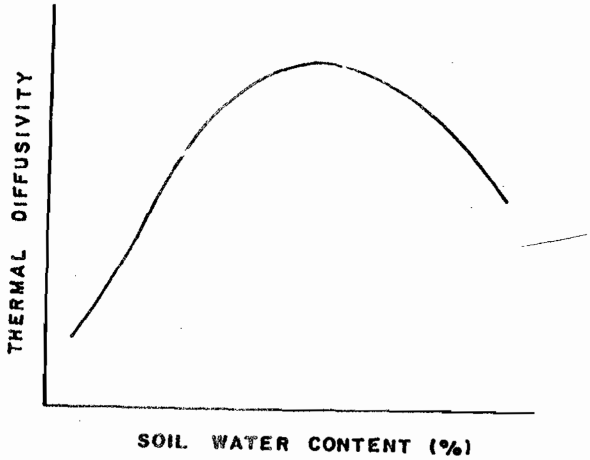

Fig. I : Variation of Thermal Diffusivity with Soil Water Content (After Kohnke, 1968)

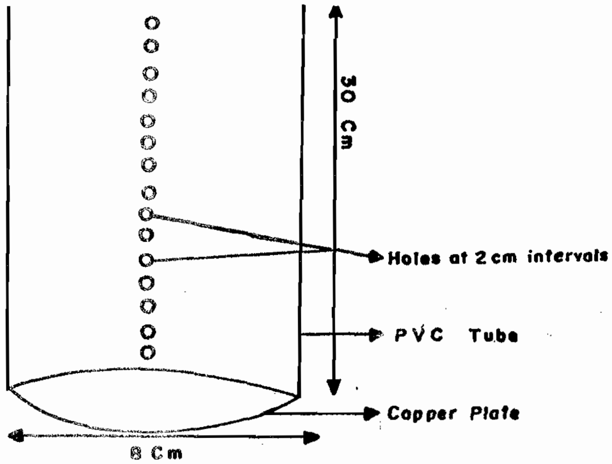

Fig. 2.0 : Diagram of the PVC Tube

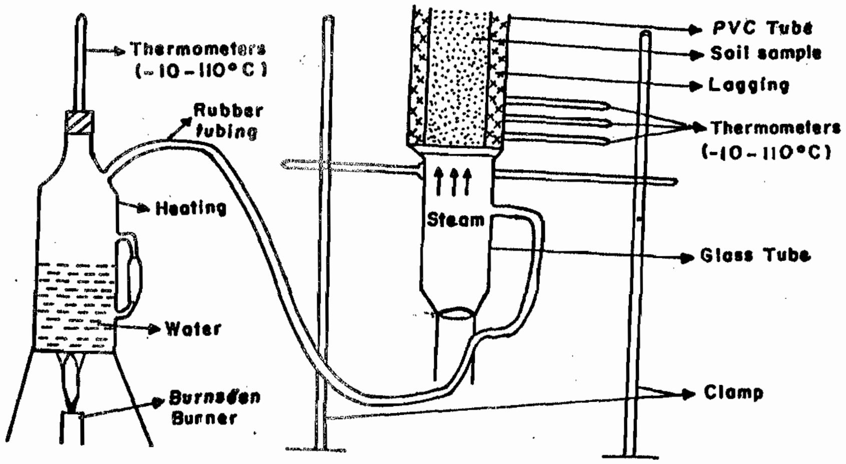

Fig. 2.1 : Diagram of the Set-Up

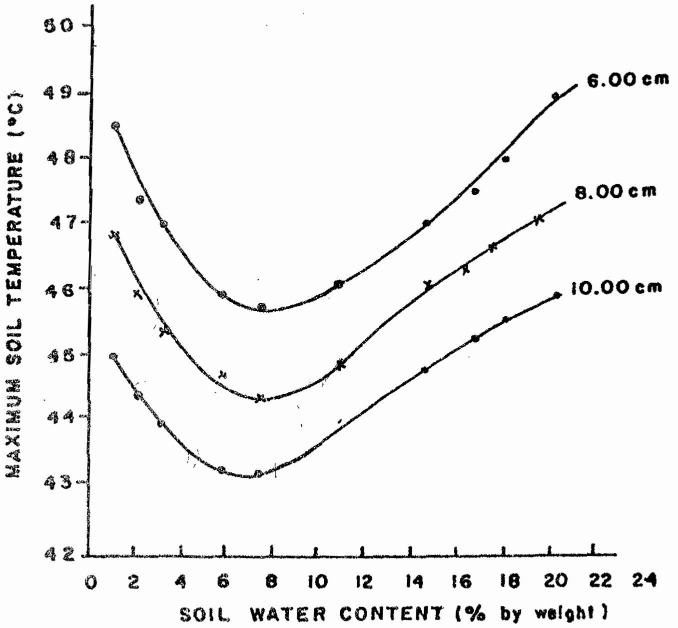

Fig. 3 : Variation of Maximum Soil Temperature with Soil Water Content

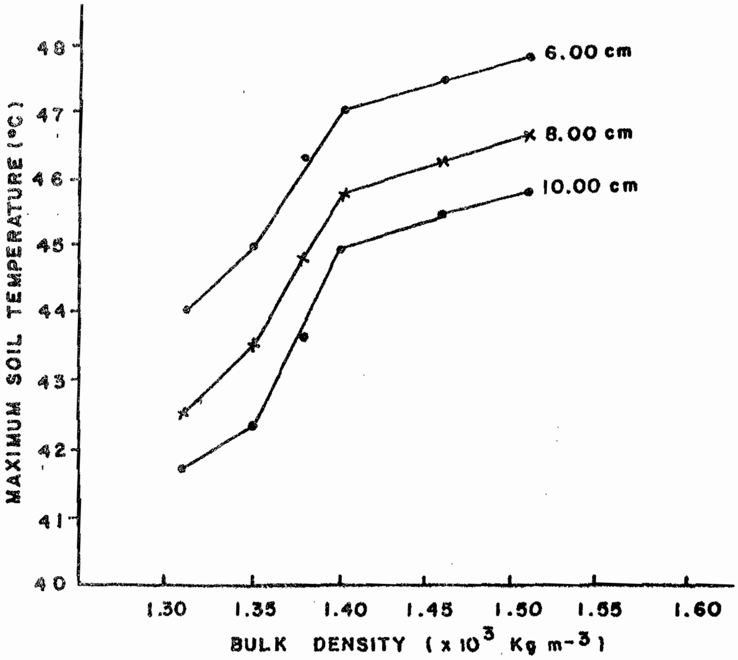

Fig. 4 : Variation of Maximum Soil Temperature with Bulk Density

It has been reported (Kohnke, 1968; Oke, 1978) that as soil moisture increased from air-dry state, soil thermal diffusivity increased sharply to a point and then decreased thereafter (Fig. 1). Soils with high thermal diffusivity allow rapid penetration of surface soil temperature changes. Thus for the same heat input, their thermal regimes are less extreme than for soils with low diffusivity. Soils with poor thermal conductivities concentrate their thermal exchanges in the upper-most layer only and consequently experience relatively extreme diurnal temperature fluctuations (Oke, 1978).

The aim of this study is to obtain information on variation of soil temperature with moisture and bulk density; and it is hoped that it will be of great importance to workers in agriculture, since soil temperature affects, practically, every phase of plant development; and the construction engineers who require knowledge of fluctuations in soil temperature in the design of roads, pipeline for sewage water (oil) and underground cable

RESEARCH METHOD AND INSTRUMENTATION

Oliviera et al (1996) reported that many studies of heat transport through soil assume that laboratory columns used in the experiment are packed homogeneously. Dense packings are frequently achieved by means of simultaneous deposition and vibration; and most researchers employing repacked soil columns appear to pack their columns dry, however, according to Oliviera et al (1996), the addition of moisture can aid in achieving a uniform packing. But moist packing means that water is present that needs to be air dry; and Baker and Hillel (1990) had dried the moistened sand packed in their infiltration chamber under infrared lamps to return it to dryness. In their experiments, the chamber was 1.3cm wide and removing the moisture required only overnight drying.

In this study, loamy sand was used for the experiment. The collected soil sample was first spread on laboratory table to air dry the initial moisture content for five days, in which period a constant weight of the soil sample was obtained. The experiment on the effects of moisture content on temperature was first conducted; varying quantities of water were sprinkled evenly over equal quantities of the air dried soil sample. Each soil sample was then thoroughly mixed to ensure uniform moisture distribution. A small amount of each soil samples was collected in a crucible and further dried in an oven overnight, for the determination of percentage moisture content (while the rest was packed into PVC tubes, Fig. 2.0).

Each of the PVC tubes was sealed at one end and the packings were done by means of simultaneous deposition and vibration (Oliviera et al, 1996). A table spoon was used to scoop the soil into the PVC tube, every two spoonful of the soil sample into the tube was followed by a gentle tap and vibration, thereby ensuring uniform bulk density, and Oliviera et al had explained that uniformity of packing is evaluated by measuring the bulk density. Eight samples were used for the experiment, and each of the soil samples was packed to a bulk density of 1.45 * 10^{3}kgm^{-3}, and was lagged with cotton wool to avoid energy loss.

After filling the tube, three thermometers (- 10 to 110°C range) were inserted at the depths of 6.00cm, 8.00cm and 10.00cm respectively from the heating end of the PVC tube (Fig. 2.1). Care was taken to ensure that the bulbs of these thermometers were along the centre of the soil column in order to monitor the temperatures along the central axis of the soil column. The PVC tube containing the soil sample was the placed on the glass tube for heating over steam as shown in Fig. 2.1. Before heating, the initial temperature of the soil sample was recorded; thereafter, temperature variations at each depth was recorded at 5 minutes interval for 45 minutes; at the expiration of the 45 minutes, the soil sample was removed and placed on a tripod-stand and temperatures monitored and recorded until it cooled. After removing the sample from the source of heat, the temperature readings were recorded at one minute intervals until cooling was observed at all depths. This helped in determining the correct times at which the maximum temperatures occurred.

The experimentation for the variation of temperature with bulk density was the same except that, the eight soil samples were in air dry state, but with varying amount of bulk densities.

CALCULATION OF PERCENTAGE SOIL MOISTURE CONTENT AND BULK DENSITY

These were calculated as follows:

(a) **Moisture Content**

Weight of empty crucible = W_A

Weight of empty crucible + moist soil = W_B

Weight of empty crucible + oven-dry soil = W_c

Weight of moist soil = $W_A - W_B = W_S$

Weight of oven-dry soil = $W_C - W_A = W_D$

Weight of moisture = $W_S - W_D = W_M$

Hence, percentage of moisture content,

$$= \frac{\text{Weight of moisture}}{\text{Weight of oven-dry soil}} * 100\%$$

$$= \frac{W_M}{W_D} * 100\%$$

(b) **Bulk Density**

Weight of empty PVC tube = W_A

Weight of PVC tube + air-dry soil = W_B

Weight of air-dry soil = $W_A - W_B = W_C$

Volume of PVC tube = V

Hence, bulk density = $\frac{\text{mass of air-dry soil}}{\text{Volume of PVC Tube}} = \frac{W_c}{V}$

RESULTS AND DISCUSSION

(a) SOIL TEMPERATURE VARIATION WITH SOIL MOISTURE

Fig. 3 shows the variation of maximum soil temperature with soil moisture for three depths: 6.00cm, 8.00cm and 10.00cm respectively.

It is evident from this figure that as soil moisture increased from air-dry state, maximum soil temperature decreased to a minimum at the hygroscopic point (i.e. about 6.5% soil moisture for loamy sand) and then increased thereafter.

As soil moisture is increased, thermal diffusivity increased to a maximum at the hygroscopic point, and decreases thereafter (see Fig. 1). Below the hygroscopic point, this increase in thermal diffusivity with soil moisture is due to the fact that addition of moisture to dry soil increases thermal contact and expels some amount of soil air. This results in a large increase

in thermal conductivity, K and a relatively smaller increase in volumetric heat capacity (ρC). The overall result is an increase in the thermal diffusivity. Beyond the hygroscopic point, however, K levels off while (ρC) continues to increase as soil moisture is increased. The result is the decrease in thermal diffusivity.

Below the hygroscopic point, maximum soil temperature decreases with increasing soil moisture while thermal diffusivity increases with increasing soil moisture. Hence, it could be deduced that maximum soil temperature decreases as thermal diffusivity increases. Above the hygroscopic point, maximum soil temperature increases with increasing soil moisture while thermal diffusivity decreases with increasing soil moisture.

From the above deductions it could be said that as soil moisture increases from the air-dry state to field capacity, maximum soil temperature varies inversely with the soil thermal diffusivity.

(a) VARIATION OF MAXIMUM SOIL TEMPERATURE WITH BULK DENSITY

Fig. 4 shows that maximum soil temperature increased with increasing bulk density. This may be explained by the fact that increasing the soil bulk density implies replacing air with soil particles. But soil particles have lower thermal diffusivity than air. Hence, increasing soil bulk density implies decreasing the thermal diffusivity of the soil sample. This results in an increase in maximum soil temperature since, as has been deduced earlier, maximum soil temperature varies inversely with thermal diffusivity.

CONCLUSION

The variability of Soil temperature with soil moisture and soil compactness is of great importance to soil scientists/engineers. The research findings show that, as soil moisture increased from air-dry state, maximum soil temperature decreased to a minimum at the hygroscopic point (which was found to be 6.5% soil moisture for loamy sand) and then increased thereafter; while thermal diffusivity increased to a maximum at the hygroscopic point and decreased thereafter. The explanation to these observed variations is given in terms of thermal conductivity as well as volumetric heat capacity of a particular soil in question. Also, there is direct correlation between soil temperature and soil compaction (which is measured in terms of soil bulk density) and this is interpreted in terms of existing pore space in different samples of soil.

Consequently, for effective agricultural practices and engineering constructions on our soils, adequate information on their temperatures, moisture contents and compaction must be gotten before project implementation.

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