The Effects of Light Intensity on Soil Depth of Different Moisture Contents using Laser Sensor

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Abstract- Laser sensing technique, a non-destructive method, has been used to determine the effect of light intensity on soil depth of different moisture contents. In this study, moisture content of clay loam and beach sandy soils were monitored using an unexpanded 5 mW Helium –Neon Laser (λ = 0.63 μm) incident through an optical fibre on one side of an equilateral triangular glass prism which was partly buried in the soil sample. The total internal reflected beam from the sample through the prism was collected from an output optical fibre into a detector and a multimeter. In calibrating the soil moisture content, various light intensities were measured with different values of moisture content in soil. A method of Specific Treatment for disturbed soil samples was used to evaluate moisture content. In relation to depth, the experimental procedures were repeated by varying the moisture at different depths- 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 and 3.2 millimeters. The output light intensities from the samples were then measured. For both sand and clay loam soils , the light intensity was found to be decreasing with increasing depth, however, the light intensity readings for sand were of higher values compared with those of clay loam. The plots for both soil samples were almost linear. Finally, the experimental results showing the decrease in light intensities with increasing depths at different moisture contents is due to the damping effects as light is propagated through the soil. Therefore, it was observed that using Laser in monitoring soil moisture with depth was limited at moisture content greater than field capacity.

Index Terms- Soil Moisture, Moisture Content, Soil Depth, Light Intensity, Total Internal Reflection, Laser

I. INTRODUCTION

Moisture storage in the upper layers of the soil profile is an important component of the total water balance of the Earth surface and is a vital state variable in any hydrological model. The soil layer that is usually considered is influenced by evapotranspiration. The depth of this layer which depends on the type of soil is typically 1-2 m. Measurement of the amount of water stored in a soil profile is essential in most water management. The application of appropriate techniques for soil water management and conservation practices requires the quantitative assessment of the soil water status. This is particularly important in agricultural water management projects and operational hydrological modeling, such as flood forecasting. For instance, in Agriculture, the variable amount of water contained in a unit mass or volume of soil and energy state of water in the soil affect the growth of plants. Numerous other soil properties depend very strongly upon water content. Among these properties are mechanical properties such as plasticity, strength, compatibility, penetrability, stickiness and trafficablity. Soil water content also governs the air content and gas exchange of the soil thus affecting the respiration of roots, the activity of micro-organisms and the chemical state of soil [1].

In many cases, particularly at the watershed scale of monitoring or modeling, soil moisture may be inferred from some hydrological variables such as rainfall, runoff and evaporation caused by temperature effect. Engmann (1990) defines soil moisture in hydrology as a system state that must be initiated and then, time wise, recomputed by increasing it when precipitation is added or decreased by drainage and evapotranspiration. In developing soil moisture models, specific bandwidth of the electromagnetic spectrum may be used. The wavelength regions which are important are the reflected visible and infrared, the thermal infrared, active microwave and passive microwave [2]. Salomonson (1983) noted that predicting hydrological state variables such as rainfall, evapotranspiration and soil moisture storage for hydrological modeling is an important means of making full use of remotely sensed data [3] . However, few researchers have applied remotely sensed soil moisture data within the framework of a hydrological model. Engman (1990) again integrated soil moisture time series into a new form of hydrological modelling. His research examined the recession response of a small basin through conceptual modelling of the subsurface flow component using the Sloan and Moore (1983) Sloping slab model. In addition, soil moisture plays an important role in the interaction between the land surface and the atmosphere [2], [4]. Dubois et al. (1995) explain that soil moisture represents a storage of water that acts as a regulator to one of the more fundamental hydrological processes, infiltration and runoff production from rainfall. Soil moisture is highly variable both spatially and temporally [5]. In order to estimate soil moisture, extrapolation of point measurements is necessary. However, recent advances in the measurement of soil moisture from space are yielding results that are promising for measuring soil moisture over large areas from satellite platforms [6]. Therefore, there is a need to determine the effect light intensity on soil depth of different moisture content using laser sensor.

II. THEORETICAL BACKGROUND

2.1 Fundamental Equations of Soil Moisture Content and Soil Depth

The “per mass” or “per volume” fraction of water in the soil can be characterized in terms of soil wetness or soil moisture content.

The mass wetness, w, is given by

$$w = M_W / M_S \quad (1)$$

where

Mw is the mass of water

Ms is the mass of dry soil.

Also, the volume wetness, θ, is the ratio of water volume Vw to the total (bulk) soil volume Vt.

Thus

$$\theta = V_w / V_t \quad (2)$$

where

the total soil volume $Vt = V_S + Vw + Va$

Vs is the volume of solids

Va is the volume of air

Vw is the volume of water

The equations (1) and (2) can be related to each other by the bulk density ρb and the density of water ρw as

$$\theta = w(\rho_b / \rho_w) \quad (3)$$

The water content of a soil profile can also be expressed in terms of depth. This is obtained by multiplying the volume wetness by the depth of the soil profile.

Therefore,

$$\theta_z = \theta . z \quad (4)$$

where

θ_z is the equivalent depth of water and

z is the depth of soil [1].

2.2 The Empirical Formula

An empirical relation can be deduced between light intensity and moisture content since the behaviour of moisture in soil seems exponential. It is observed that the light intensity increases as moisture content increases for the following soil samples at undisturbed states: Clay loam and Beach sand.

Thus the expression is given by

$$I = a \exp(b\theta_g) \quad (5)$$

The expression finally becomes

$$\ln I = \ln a + b\theta_g \quad (6)$$

where I is the light intensity across the soil sample, θ_g is the moisture content by mass and *a* and *b* are constants. This is the regression equation for the soil samples and it differs from the type of soil sample, since the constants differ. The correlation between light intensity and moisture content for the soil sample resulted in a highly significant (r^2 =0.99).

III. EXPERIMENTAL SET UP AND PROCEDURE

About 360g of each of the samples were weighed and recorded. Five grams of water was added to each of the samples and mixed uniformly in a glass container and the total mass was measured and recorded. Fifty grams of each of the disturbed samples were put into separate crucibles. The moisture content of each sample was determined by gravimetric method : The samples were initially weighed , after which they were oven-dried at 105 degree Celsius for 24 hours and reweighed to determine the change in mass. Hence the moisture content of each sample was determined by finding the change in mass before and after oven-dried. It was then expressed as percentage moisture content by mass. The remaining moist soil samples were packed into separate beakers and the optical method was performed to determine the light intensities across each sample. This method was known as Specific Treatment. The beam from the He-Ne laser source was then coupled into fiber 1.The emerging beam from fiber 1 was incident at a critical angle of 62^o after total internal reflection had occurred at one of the reflecting surfaces of the glass prism placed 2 mm inside the moist packed samples.

This beam after being totally internally reflected by the prism surface was carried further by fiber 2 to the detector and the light intensities across each sample were determined using multimeter. The water content of each sample was increased for five (5) additional times in steps of five (5) grams. While the same mass of each sample was taken and oven-dried to determine the change in mass, their corresponding light intensities by the laser source were measured respectively by repeating the above optical procedure. The percentage moisture content by mass was then calculated for each soil sample.

In relation to depth, the experimental procedures were repeated by varying the moisture at different depths- 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 and 3.2 millimeters. The output light intensities from the samples were then measured. In order to dry and evaporate water from the soil, a 60 Watts incandescent light and a fan were placed above the soil sample container and made to operate simultaneously.

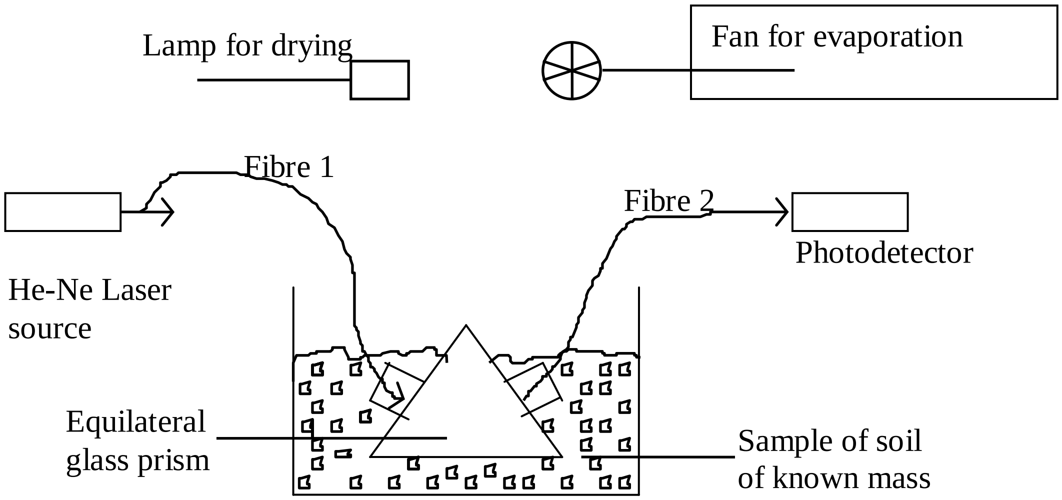

Figure (1): Experimental System Set-up

IV. RESULTS AND DISCUSSIONS

A. The Relationships between Light Intensity and Moisture Content For Disturbed Clay loam

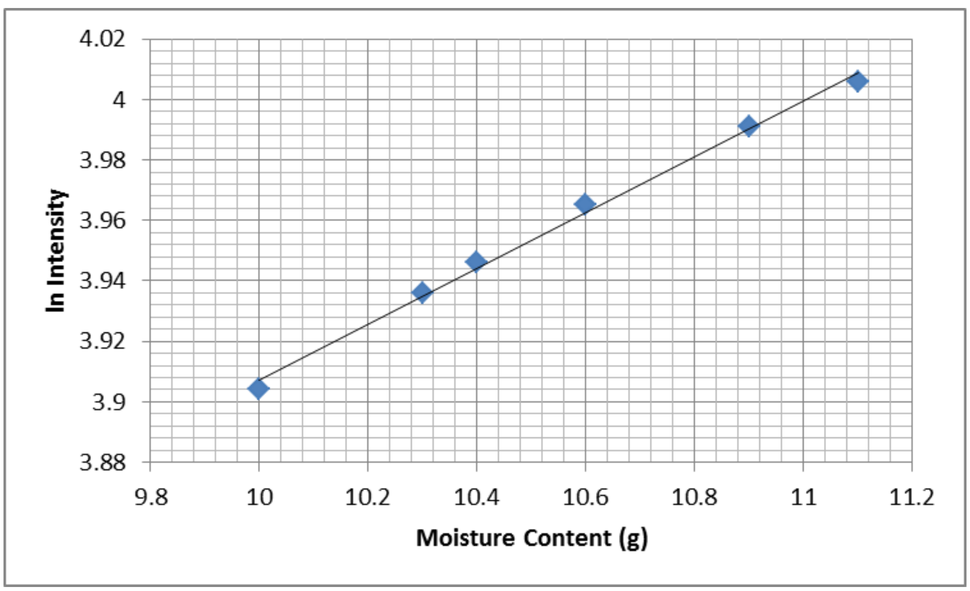

Fig 2: Graph of natural log of Light Intensity with Moisture Content for Disturbed Clay Loam

B. The Relationships between Light Intensity and Moisture Content for Disturbed Sand

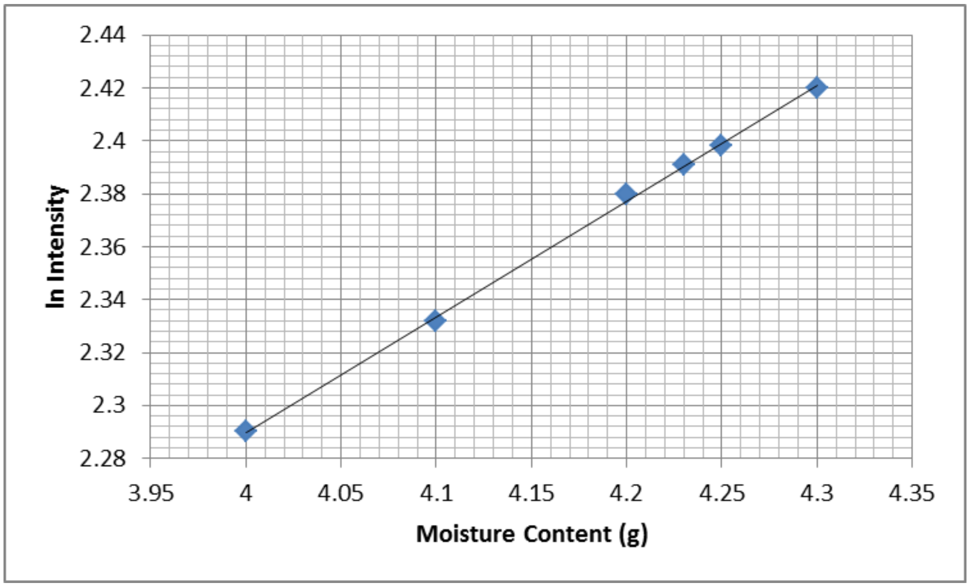

Fig 3 : Graph of natural log of Light Intensity with Moisture Content for Disturbed Sand

It was found from the plots of both samples that the light intensity was increasing with increasing moisture content. Also, the light intensity readings for clay loam soil were greater than that of beach sand. The values of moisture content and light intensity for disturbed clay loam were found to be greater than that of disturbed beach sand. The plots were found to be linear and the relationship between the light intensity (arb.units) and moisture content was a positive exponential function which follows a relationship of $I=a\exp(b\theta_g)$, where a and b are constants perculiar to a particular soil and "a" was evaluated to be intensity value at which minimum moisture occurs.

C. The Relationships between Light Intensity and Soil Depth for Disturbed Soils of different Moisture Contents

(i) Dry Soil (0g Moisture Content)

The plot of values of light intensities and their corresponding depths for sand and clay loam soils with 0 gram (dry soil) of moisture content each are shown in figure 4. For both sand and clay loam soils , the light intensity was found to be decreasing with increasing depth, but the light intensity readings for sand were of higher values compared with those of clay loam both at disturbed state. The plots for both soil samples were almost linear.

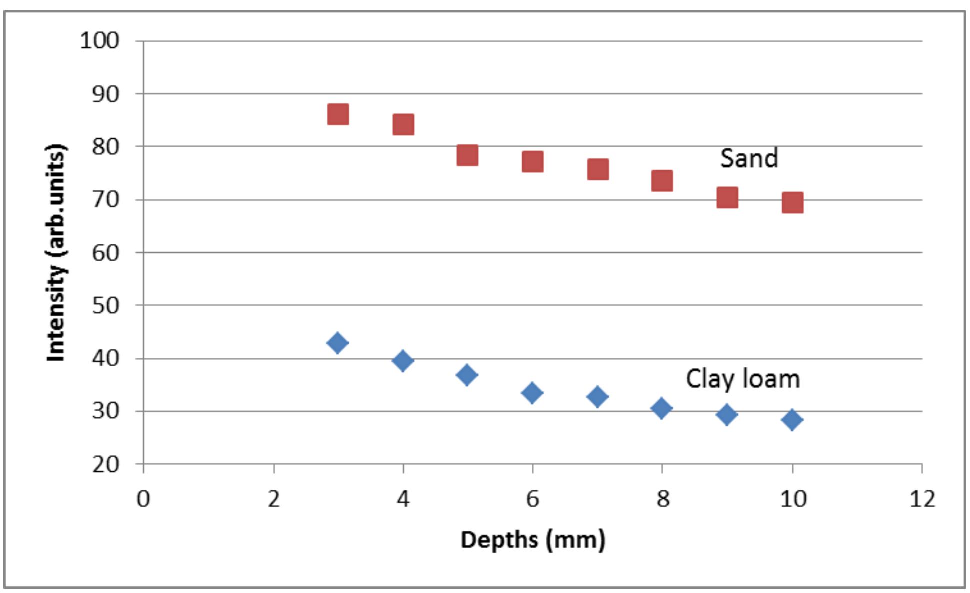

Fig. 4: A graph of light Intensity versus Depth for disturbed Clay loam and Beach Sand with 0g of moisture content

(ii) 5g of Moisture Content

The plot of values of light intensities and their corresponding depths for sand and clay loam soils with 5 grams of moisture content each are shown in figure 5. For sand and clay loam soils, the light intensity readings were found to be decreasing with increasing depth. The plots were also found to be almost linear.

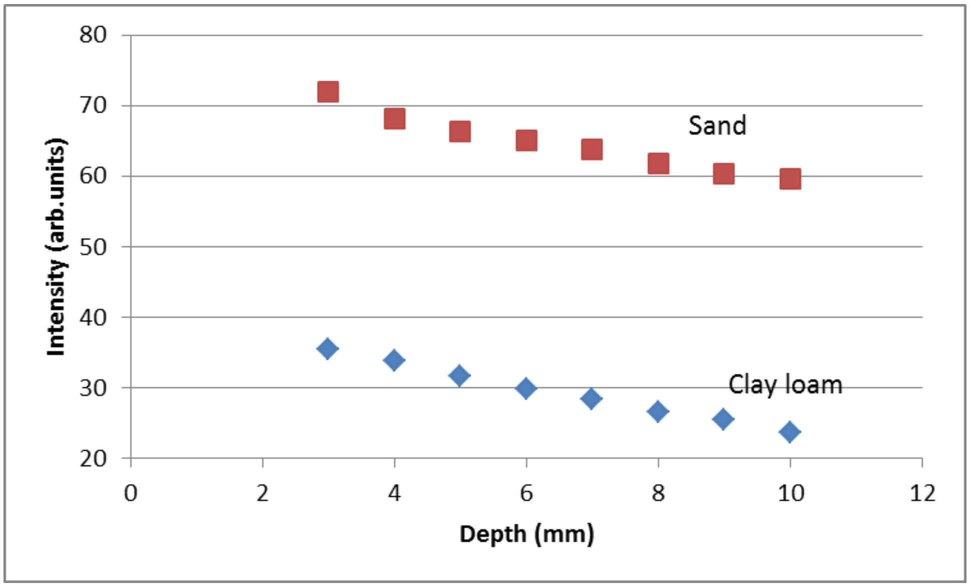

Fig. 5 : A graph of light Intensity versus Depth for disturbed Clay loam and Beach Sand with 5g of moisture content

(iii) 10g of Moisture Content

The plot of values of light intensities and their corresponding depths for sand and clay loam soils with 10 grams of moisture content each are shown in figure 6. For sand and clay loam soils, the light intensity values were also found to be decreasing with increasing depth. The light intensity readings for these soil samples were also varied within a chosen depth range. The plot of the sand was not linear but that of clay loam was found to be almost linear.

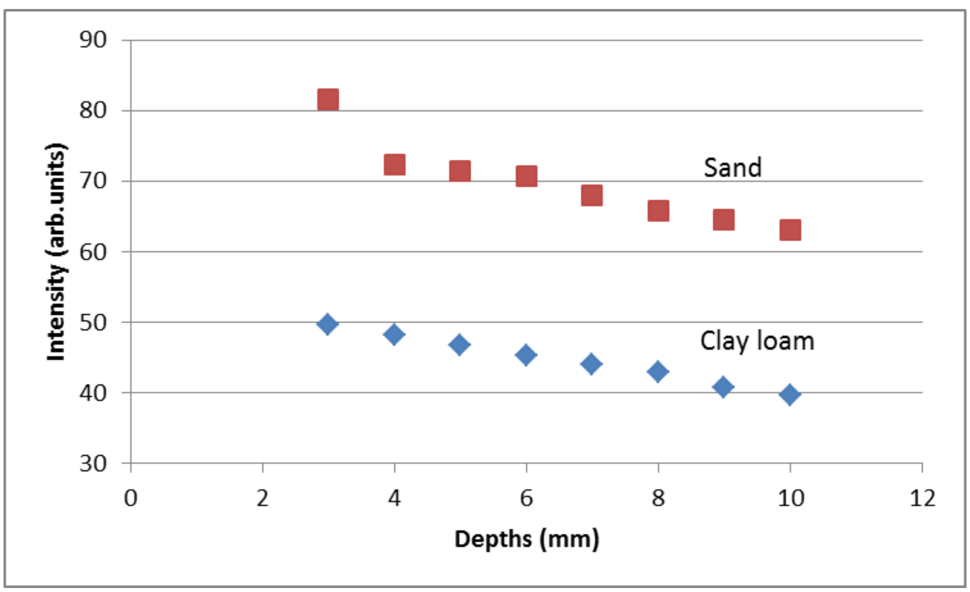

Fig. 6 : A graph of light Intensity versus Depth for disturbed Clay loam and Beach Sand with 10g of moisture content

D. Effects of Light Intensity on Soil Depth for the Disturbed Soil Samples of different Moisture Contents

For the dry soil (0g) samples, it was found that the higher values of light intensity on depth were due to the nature of the soil sample. The sandy soil with more coarse sand than the clay loam has higher values of light intensity readings than the clay loam soil with less coarse sand, hence greater values of moisture content were obtained. In the case of five grams (5 g) of moisture content in the soil samples, it was found that sand has higher values of light intensity readings as compared with that of clay loam, although both soil samples have their light intensity readings decreasing with increasing depth. This could be explained to the fact that the soil samples have different compositions and pores that allow slippage of water through them. Also, this might contribute to the behaviour of the plots of the soil samples. Again, in the case of ten grams (10g) of moisture content in the soil samples, it was found that the light intensity readings of sand were higher than that of clay loam soil, although their light intensity readings decreased with increasing depths. This might be due to the similar reasons discussed above. It was also observed that the increase in moisture content causes a change in the light intensity readings of the soil samples.

Finally, the decrease in light intensity readings with increasing depth in all cases could be due to the damping effects as the light is propagated through the soil. Various factors such as soil organic matter and soil texture might have contributed to this damping effect.

V. CONCLUSION

The effects of light intensity on soil depth were analyzed using the laser beam. The laser sensing instrument that uses prism as a sensor relies on the variation of moisture from the soil on the prism surface. This is monitored using the intensity of light from laser source onto the water-glass interface based on the total internal reflection. The light intensity is independent of the soil type. The Specific treatment method of measurements was used for the soil samples to evaluate the moisture content. In relation to the penetration depth, the experimental results showed that the light intensity decreases with increasing depth at different moisture contents due to the damping effects as the light is propagated through the soil. Therefore, it was observed that Laser sensing technique was limited at moisture content greater than field capacity.

REFERENCES

[1] Hillel. D. (1980) Fundamentals of Soil Physics. Academic Press, Inc, Harcourt Brace Jovanovich, Publishers, Page 123-124, 134-137.

[2] Engman, E. T. (1990). Use of Microwave Remotely Sensed Soil Moisture in Hydrological Modelling.In application of Remte Sensing in Hydrology,ed G.W.Kite and A Wankiewiez 279-292 Proc. Symp. No. 5, NJRI Saskatoon,Canada.

[3] Salomonson, V.V. (1983). Water Resources Assessment. In: Manual of Remote Sensing, ed J. Colwell, 1497-1570. Am. Soc. Photogramm Remote Sensing.

[4] Sloan, P.G and Moore, I.D.(1983). Modelling Subsurface Stormflow on Steeply Sloping Forested Watersheds. Water Resouces Res. 20(12), 1815-1822.

[5] Dubois, P.C., van Zyl, J. and Engman, E. T.(1995). Measuring Soil Moisture with Imaginary Radar. IEEE Trans Geoscience Remote Sensing. 33.915-926.

[6] Wood, E. F., Lin, D. S., Mancini, M., Thongs, D., Troch, P. A., Jackson, T. J., Famiglietti, J. S. and Engman, E. T. (1993). Intercomparisons between Passive and Active Microwave Remote Sensing and Hydrological Modelling for Soil Moisture. Advanced Space Research 13(5), 167-175.

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