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Determination of Soil Temperature Variations with Time Based On Air Temperature and Effects on Climate

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Abstract
Variations of soil and air temperature in the lower atmosphere directly affect Earth processes such as soil activities, biological activities, climate change and the mean temperature of the Earth with respect to Global warming. While the air temperature of a given region can be easily measured on any scale, the processes and technicality required in the measurements and data acquisition of soil temperature on a large scale is cumbersome leading to scarcity in soil temperature data. The daily mean values of air and soil temperature for each month was plotted on a scatter plot and the coefficient of correlation was computed. A regression analysis was then used to establish a relationship between the two data set and generate equations for determining the dependent variable from the independent variable. The process was also repeated for the monthly mean values of the soil and air temperature data. Correlation coefficients computed from the graphs of the daily mean soil and air temperature fell between 0.3 and 0.9 for almost all the month in the year under study while the graph of the monthly means air and soil temperature values produced a yearly correlation coefficient of 0.722 and 0.689 for the conditional and unconditional data set respectively indicating the feasibility of a general model.
Key Words: *Atmosphere, Temperature, Global Warming and Spatial-temporal*

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I. Introduction

Soil temperature, an important weather parameter influences soil biological processes such as seed germination (Dwyer et al., 1990), seed implantations (Zogg et al., 1996), root respiration (Burton et al., 1998), plant' s root rate, plant water and nutrient intake (Kaspar & Bland, 1992), bio-decomposition rate and soil respirations (Leirós et al., 1999)., soil physical processes such as hydraulic conductivity and mode of nutrients and chemicals migration in soil profiles (Grundmann et al., 1995; Ren et al., 2014; Vigil & Kissel, 1995) and soil chemical processes such as its Cat-ion Exchange Capacity (CAC), available phosphorus level and soil pH (Onwuka, 2016). Soil temperature is also an important indicator of climate change and an essential parameter in the field of Geotechnical and Geoenvironmental Engineering (Qian et al., 2011). Significant effects of soil temperature variations on soil weathering process and global warming further upholds its importance as a weather parameter whose data must be readily available (Gislason et al., 2009; Jungqvist et al., 2014).

Air temperature is an important climatic parameter, which is directly related to soil temperature (Jungqvist et al., 2014). An increase in soil temperature generally follows an increase in air temperature. This is because both are determined by the energy balance at the ground surface (Buringh, 1984; Pritchett & Fisher, 1987), but the relationship is often nonlinear and depends on the soil type and profile as well as the soil cover (P. Sharma et al., 2010). Reliable and consistent soil temperature data are required by researchers in the field of climate change, carbon sequestration, Agrophysics, and geology, but soil temperature is often difficult to monitor in Spatio-temporal levels as installation of soil temperature measuring equipment in soil profile not only expensive but also tedious (Brenna et al., 2005; Kang et al., 2000). Developing suitable site specific model for predicting soil temperature from air temperature data obtained from the site could decrease the amount of time, energy, and cost necessary for on-site monitoring of soil temperature. This method has often been used alongside other parameters to estimate soil temperature for a given site by several researchers (Gupta et al., 1983; Kang et al., 2000; Toy et al., 1978; Victor R. Hasfurther & Robert D. Burman, 1974; Zheng et al., 1993). Earlier research has shown that a correlation exist between the daily mean soil temperature and daily mean air temperature of a given region or area as they are both determined by the energy balance at the ground surface and thus, this correlation if carefully observed can be used to develop a general and effective model that can be used to obtain estimated values of soil temperature for a given region from the air temperature data of that region.

This paper examined the relationship between air and soil temperature data for a particular site by comparing conditional and unconditional air and soil temperature data obtained from an Automated Weather Station located at a chosen site and understudy the level to which real air temperature data correlates with real soil temperature data taken at the same instant of time. It will also validate the theoretically expected strong correlation between the observed atmospheric air temperature and the observed soil temperature in a particular region.

II. Material and Methods

Soil and air temperature data grouped were as conditional with respect to zero temperature and unconditional with respect to zero temperature. Detailed knowledge and information of these variations are required by researchers to understudy Earth processes and predict trends of future events or special occurrences. The data used in this study was a year data of air temperature and soil temperature measurements collected by the Nigerian Environmental Climactic Observing Program (NECOP) station situated at University of Lagos, Nigeria (6.455027°N, 3.384082°E). This station is capable of measuring and storing weather parameters such as air temperature (°C), relative humidity (%), precipitation (mm), atmospheric pressure (mbar), wind speed (m/s), wind direction, solar radiation (W/m^2), soil moisture (%), soil temperature (°C), rain rates (mm/mm) and other derived weather variables.

The station is equipped with the integrated sensor suite, a solar panel (for power generation) and the wireless console. Data collected and stored by the weather station are downloaded to a computer via the console. The Integrated Sensor Suite (ISS) houses the sensors for air temperature, soil temperature and Sensor Interface Module (SIM). The SIM contain the electronic circuitry that convert the signals from the sensors into meaningful weather parameters and store them in specific memory blocks for easy transmission or download via the console.

Values corresponding to the air temperature and the soil temperature at a depth of 10cm for the year 2009 sampled at an interval of 5 minutes were obtained from the NECOP weather station. The mean air and soil temperature were extrapolated from the maximum and minimum air and soil temperature for both unfiltered and filtered data (in which the zero occurrences of air temperature has been removed). The correlation coefficients for the two variables were calculated using the Pearson’ s formula for correlation coefficient (r) which is an accurate pointer of the interdependence of the two variables and is given by the equation;

$$r=\frac{\sum_{i=1}^{n}(X_i-\bar{X})(Y_i-\bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i-\bar{X})^2\sum_{i=1}^{n}(Y_i-\bar{Y})^2}} \quad (1)$$

where $\bar{X}$ and $\bar{Y}$ are the sample mean of the data series variables X_i and Y_i (Zou et al., 2003).

A scatter plot of the two variables in all the data series was plotted and a linear regression analysis was used to study the linear relationship between the independent (air temperature) variable and the dependent (soil temperature) variable in every set. Viable model equations that can be used for predicting estimated values of soil temperature from simple given air temperature data were also generated from the regression analysis.

III. Results

The daily mean air and soil temperature was computed from the daily averages of the minimum and maximum air and soil temperatures while the monthly and yearly mean were computed from the daily and monthly mean of air and soil temperatures respectively. A scatter plot was generated for each data set and the correlation coefficient (R) for each set is shown on its corresponding scatter plot. A correlation value of +1 indicates perfect positive correlation, while -1 indicates perfect negative correlation. A correlation value of 0 implies that there is no association, 0.2 indicates a weak correlation, 0.5 indicates a moderate correlation and 0.8 indicates strong correlations while the + and - signs represents positive and negative correlation respectively (Zou et al., 2003).

The conditional with respect to zero data were analyzed without zero temperature value in the calculation of daily and monthly means. The corresponding scatter plots for daily mean (January to December) are shown in the figures 1 to 12. The unconditional with respect to zero temperature data were analyzed with zero temperature value in the calculation of daily and monthly means. The corresponding scatter plots for daily mean for the months of January to December are shown in figures 14 to 25. The scatter plot for the monthly mean air and soil temperature for the conditional data is shown in figure 13 while the plot for the unconditional data is shown in figure 26.

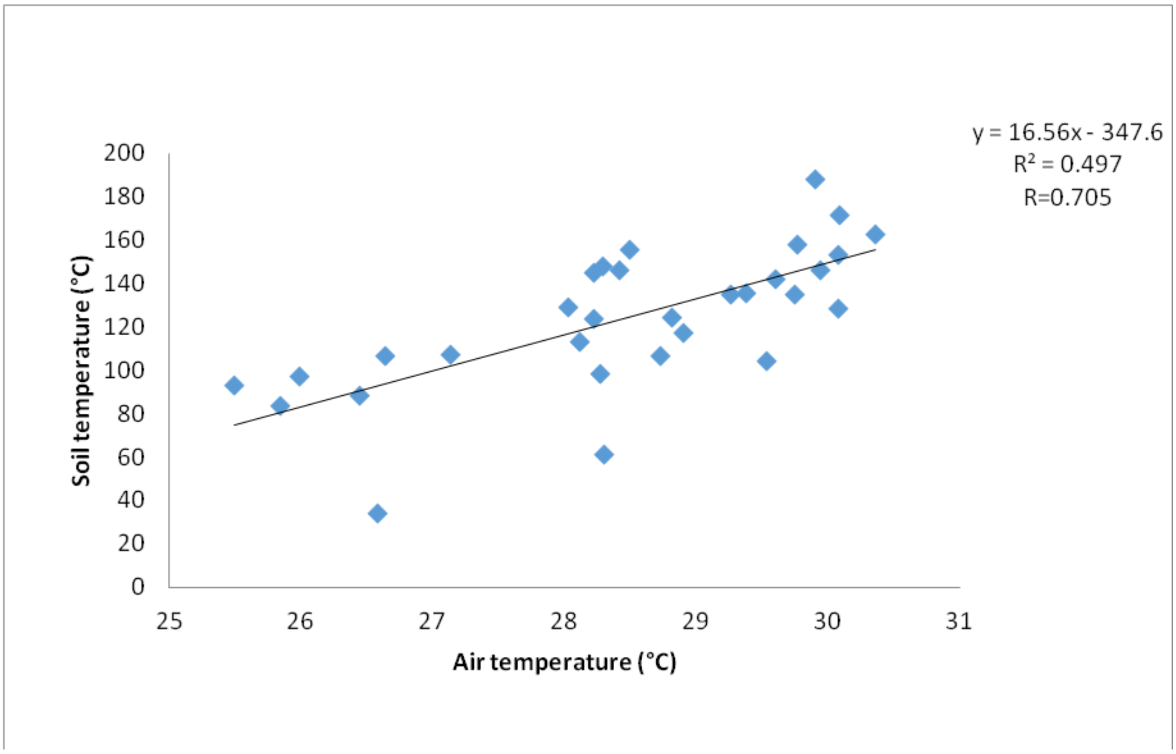

Figure 1: Graph of daily mean soil temperature against daily mean air temperature for January

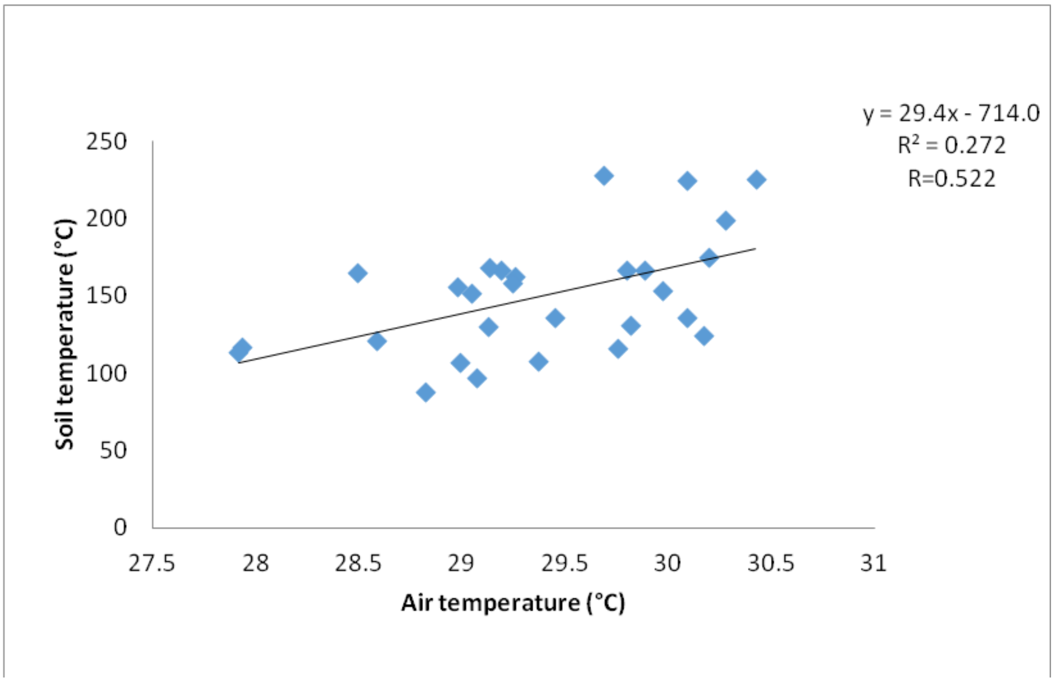

Figure 2: Graph of daily soil temperature against daily mean air temperature for February.

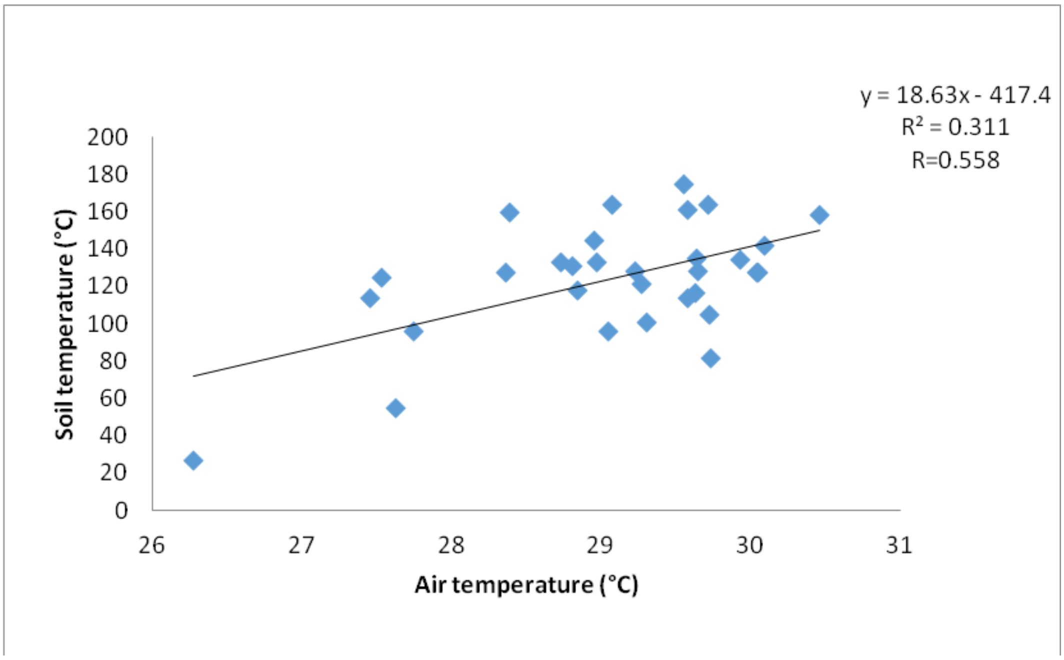

Figure 3: Graph of daily mean soil temperature against daily mean air temperature for March.

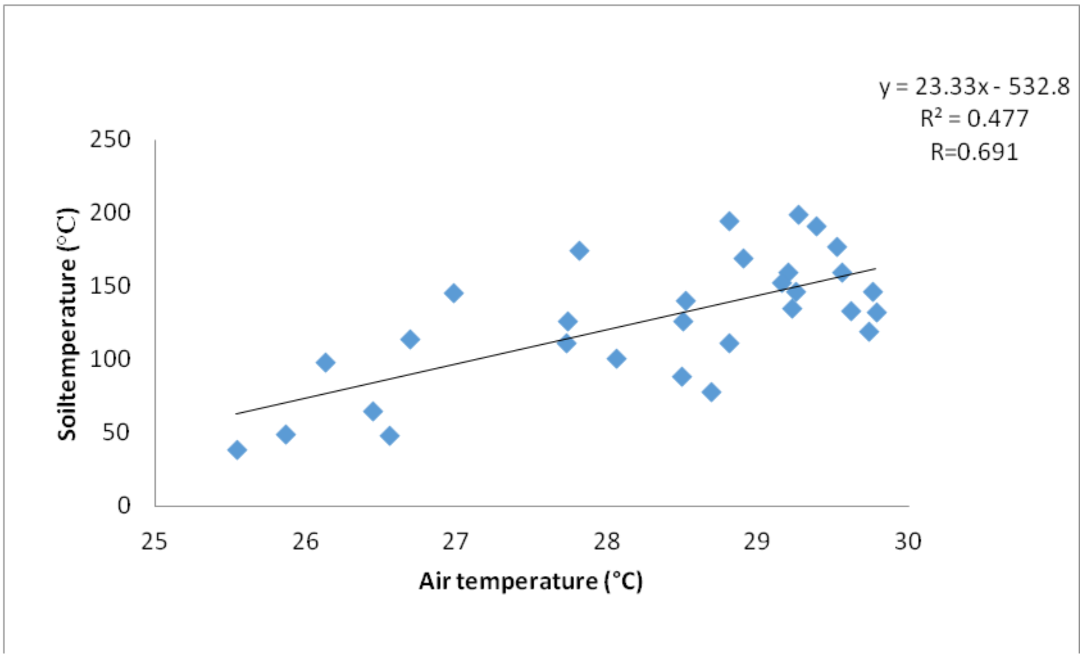

Figure 4: Graph of daily mean soil temperature against daily mean air temperature for April.

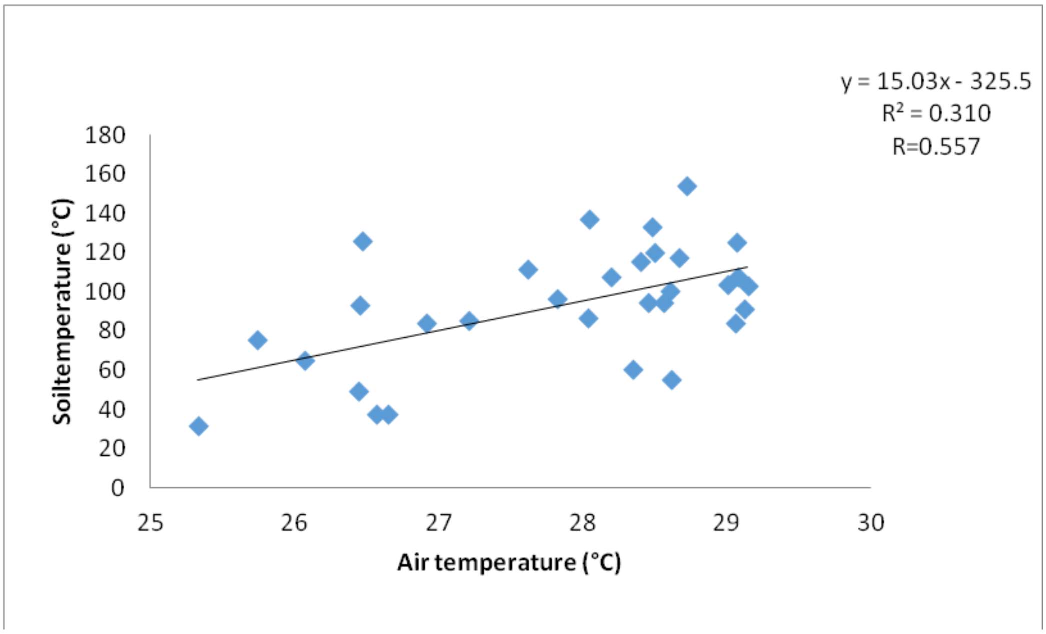

Figure 5: Graph of daily mean soil temperature against daily mean air temperature for May.

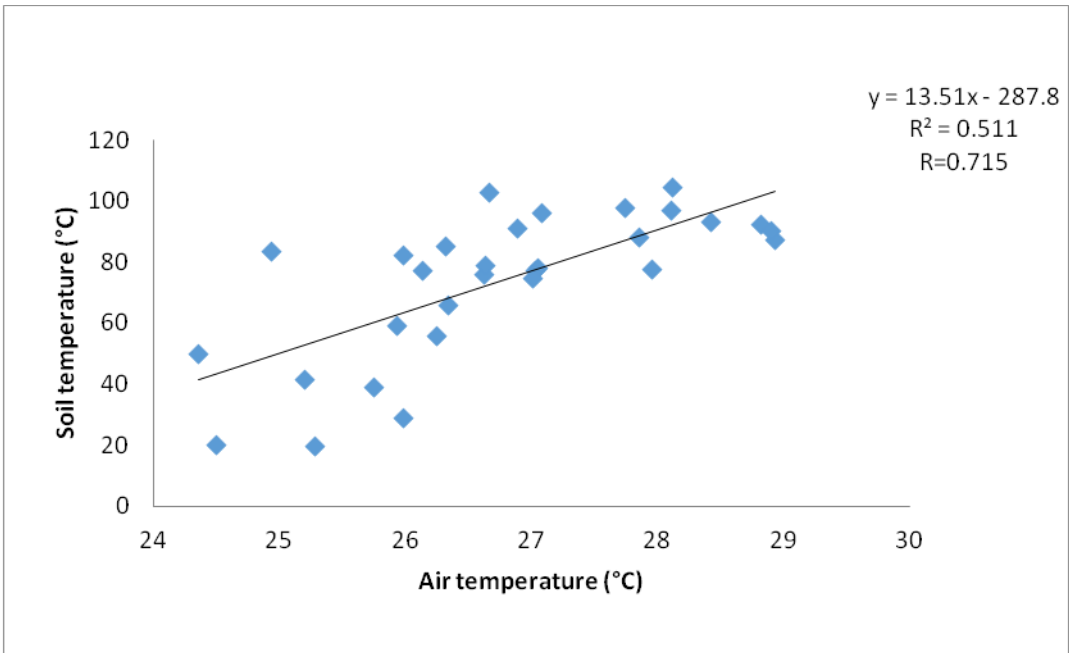

Figure 6: Graph of daily mean soil temperature against daily mean air temperature for June.

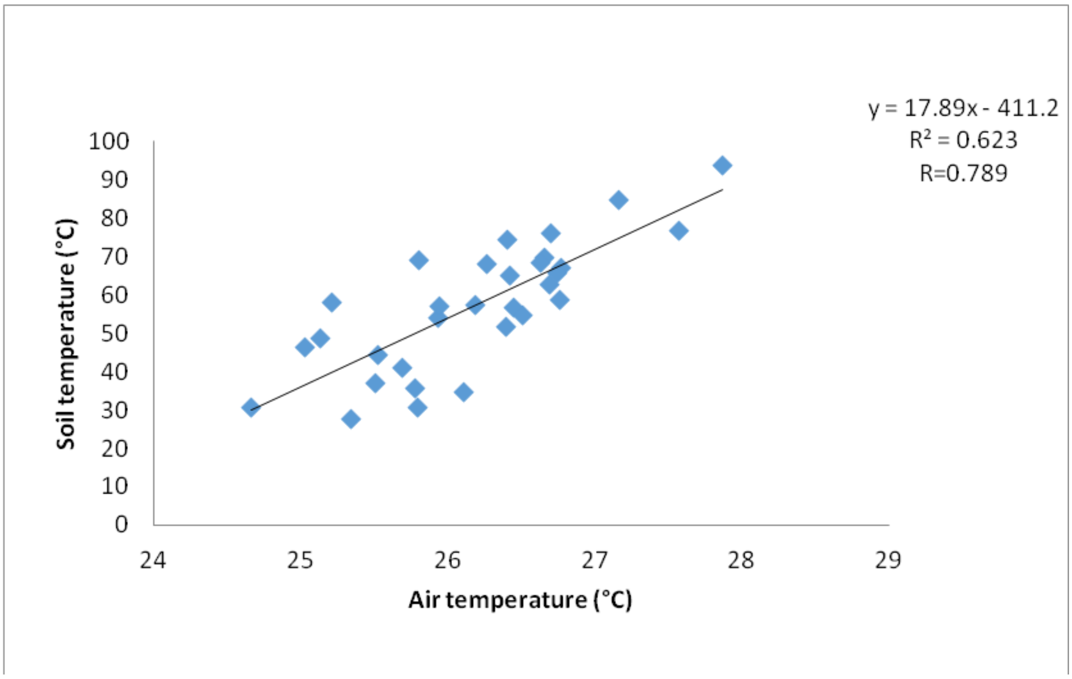

Figure 7: Graph of daily mean soil temperature against daily mean air temperature for July

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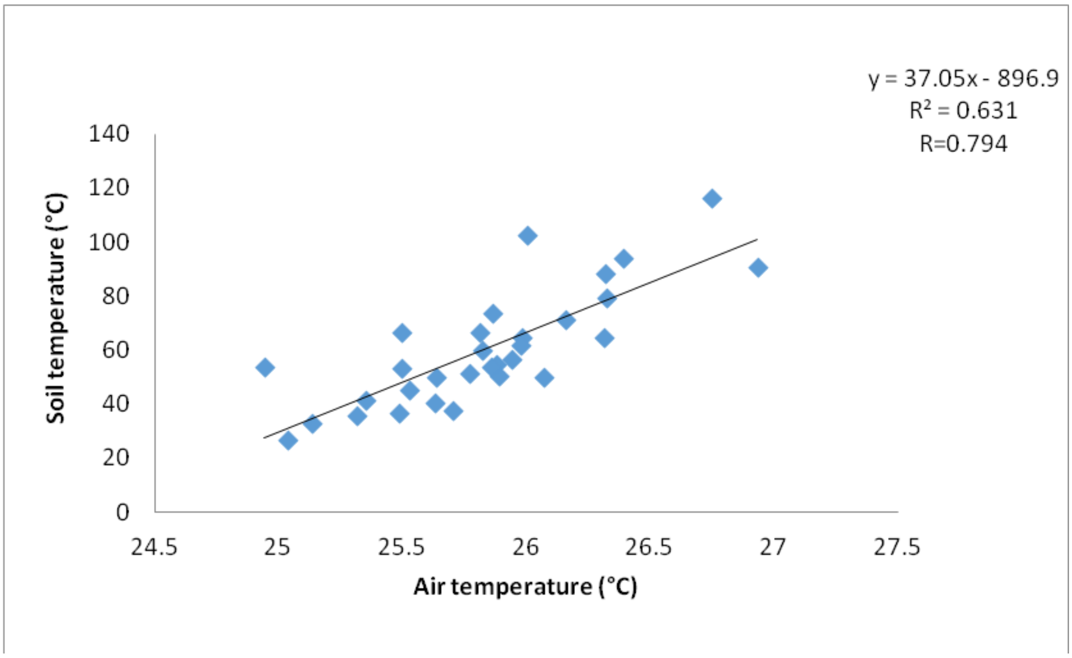

Figure 8: Graph of daily mean soil temperature against daily mean air temperature for August.

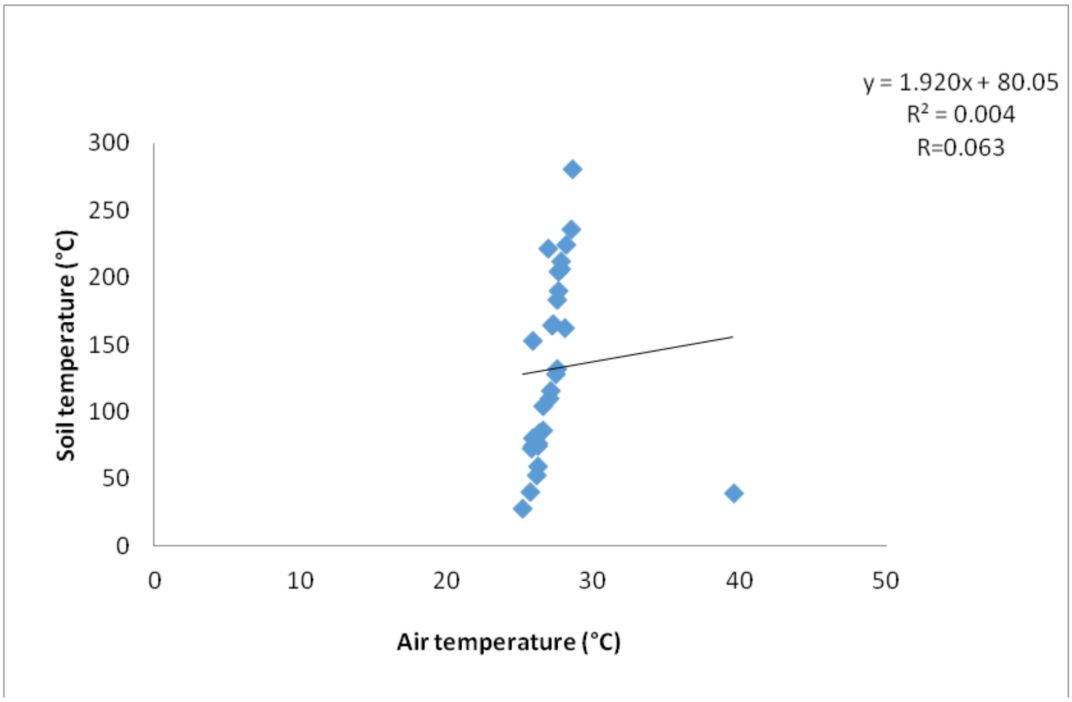

Figure 9: Graph of daily mean soil temperature against daily mean air temperature for September.

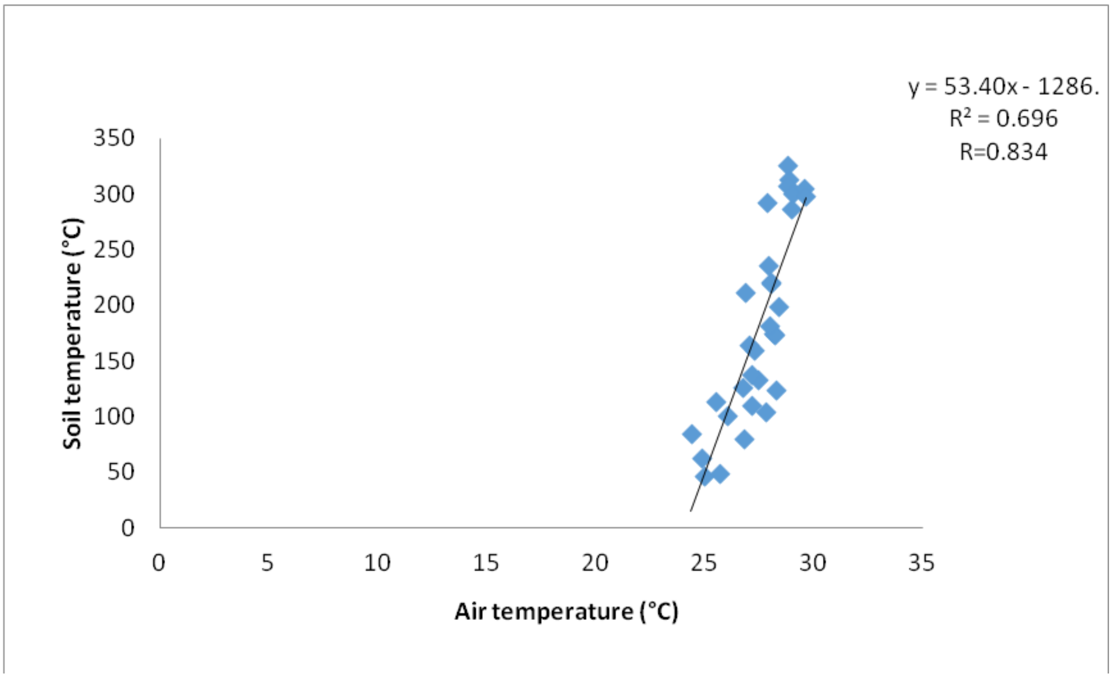

Figure 10: Graph of daily mean soil temperature against daily mean air temperature for October.

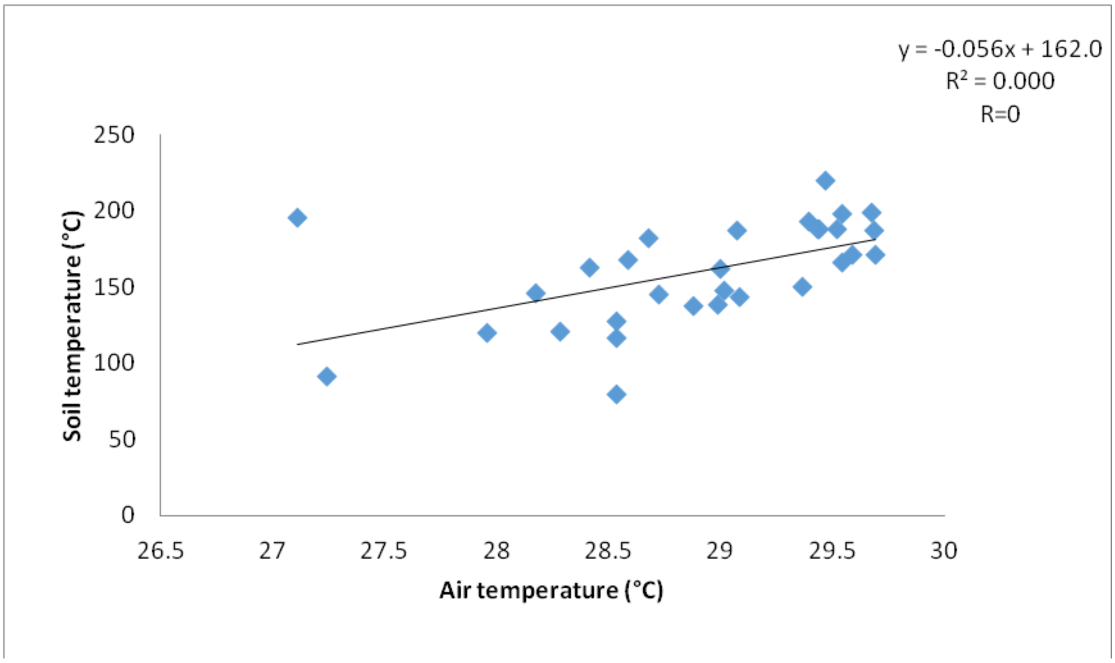

Figure 11: Graph of daily mean soil temperature against daily mean air temperature for November.

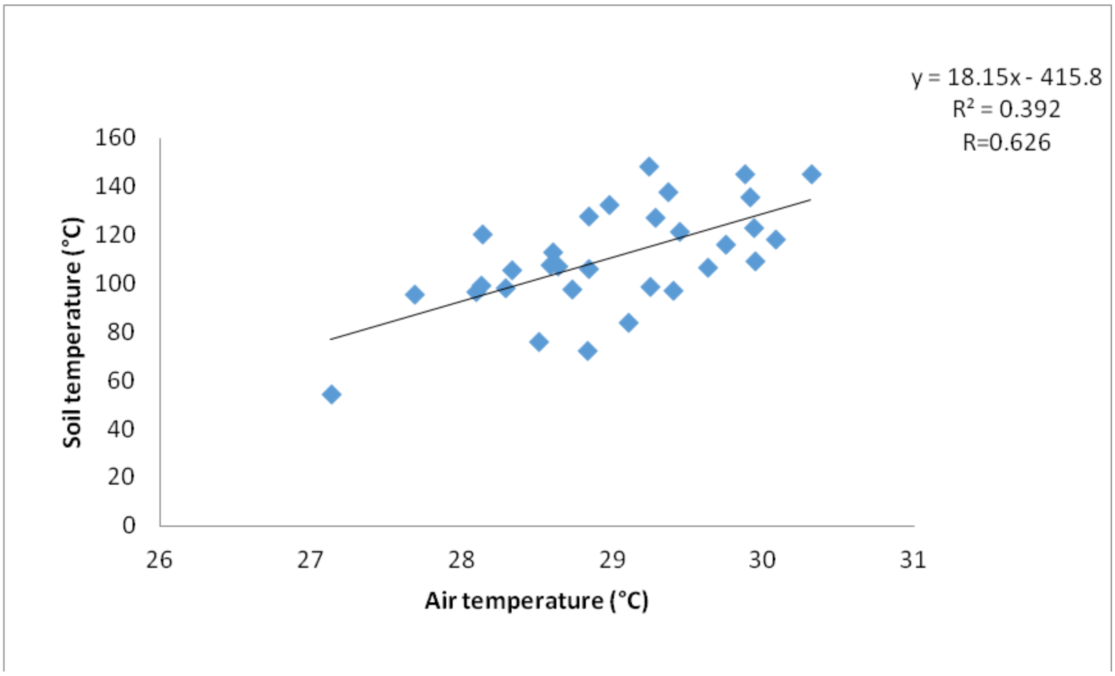

Figure 12: Graph of daily mean soil temperature against daily mean air temperature for December.

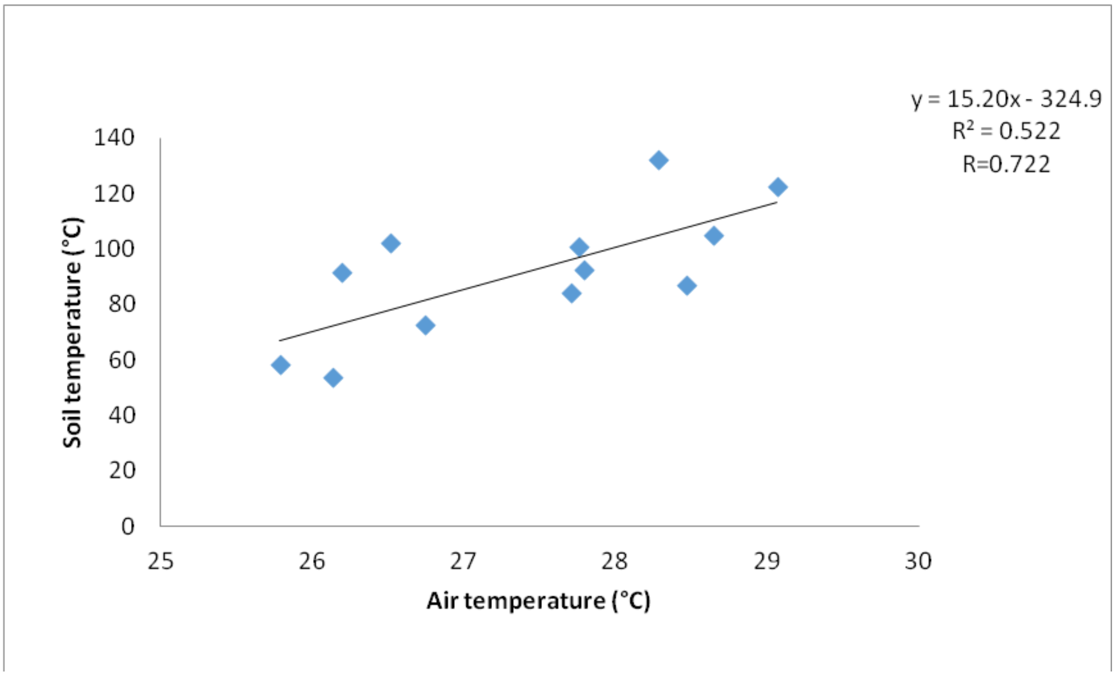

Figure 13: Graph of monthly mean soil temperature against monthly mean air temperature for the year 2009

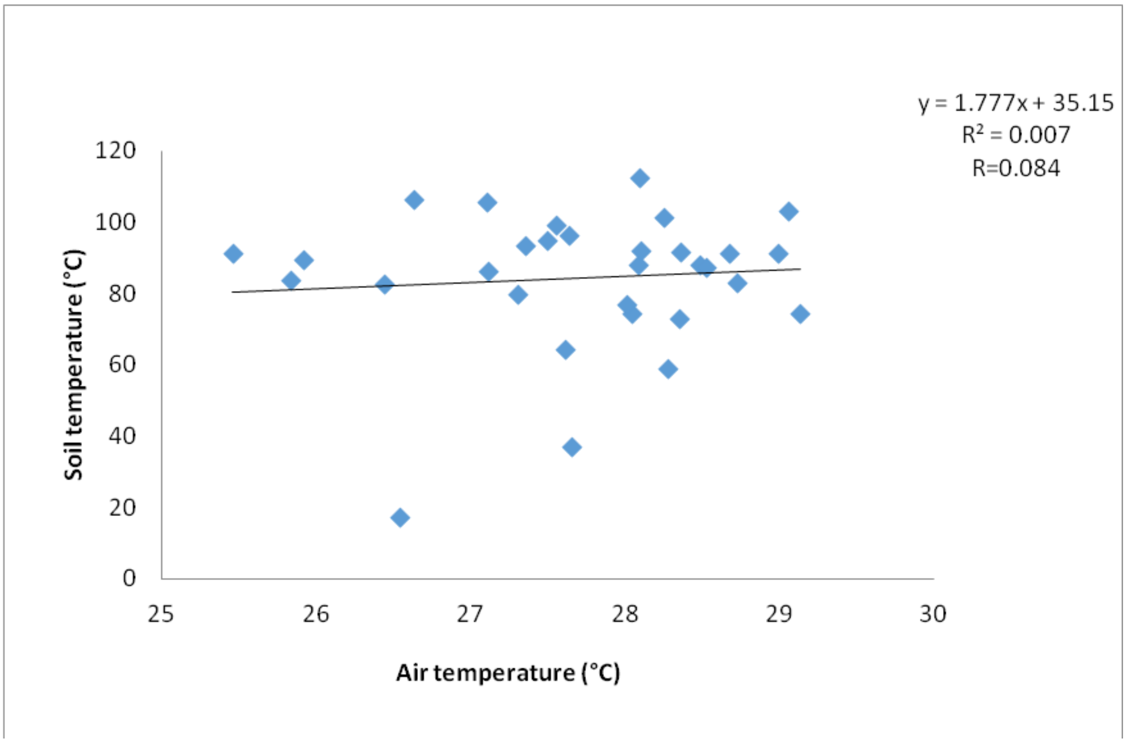

Figure 14: Graph of daily mean soil temperature against daily mean air temperature for January.

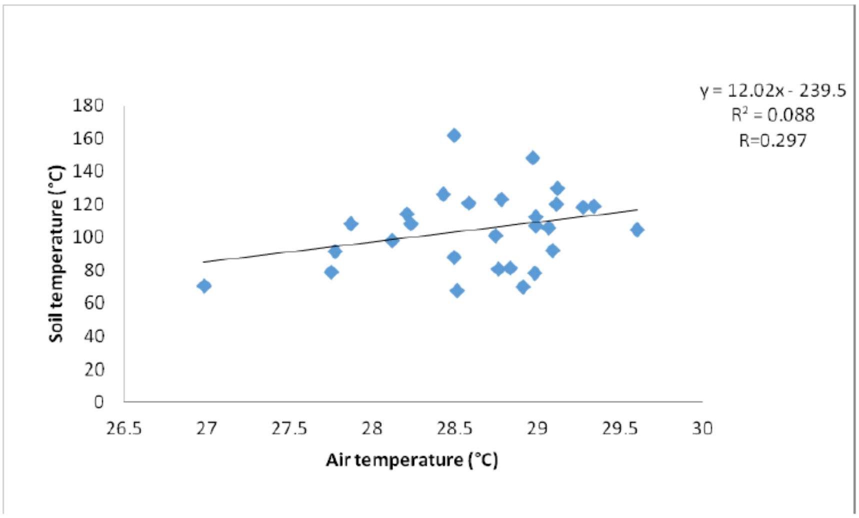

Figure 15: Graph of daily mean soil temperature against daily mean air temperature for February

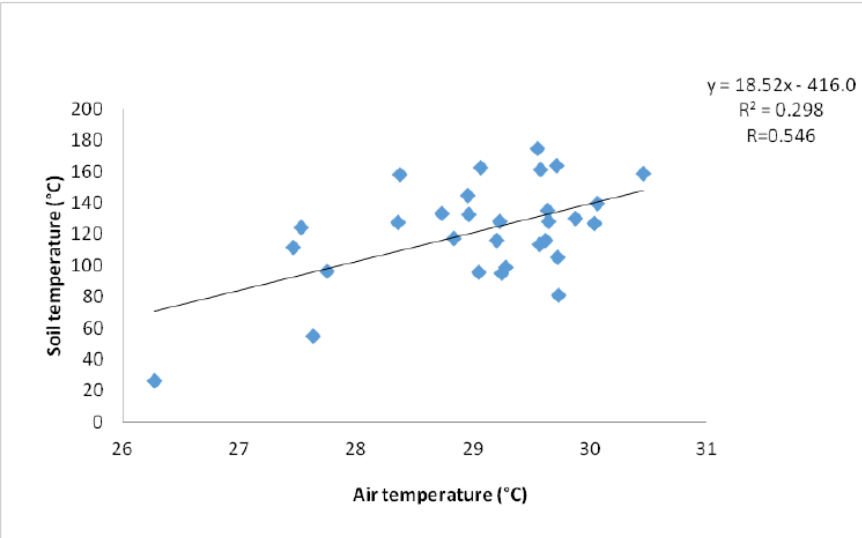

Figure 16: Graph of daily mean soil temperature against daily mean air temperature for March.

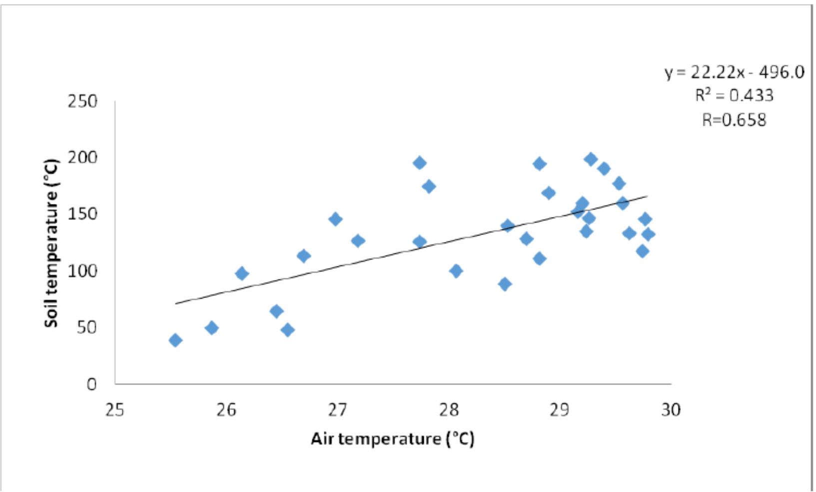

Figure 17: Graph of daily mean soil temperature against daily mean air temperature for April.

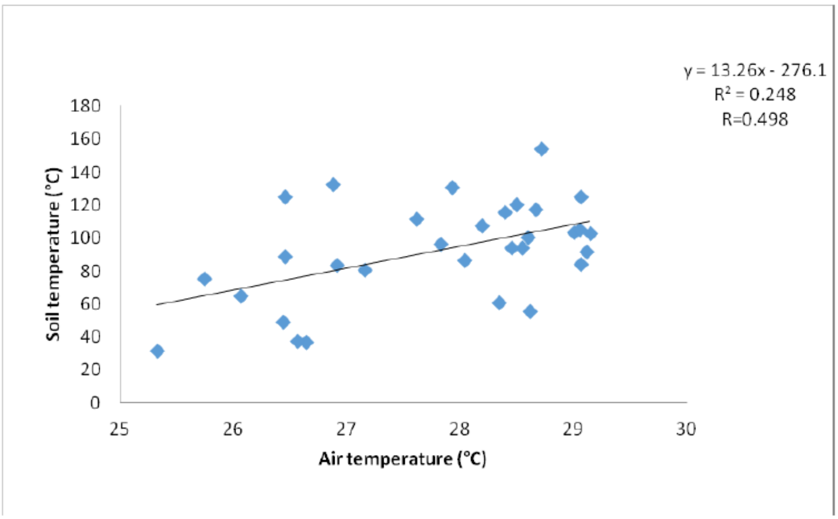

Figure 18: Graph of daily mean soil temperature against daily mean air temperature for May.

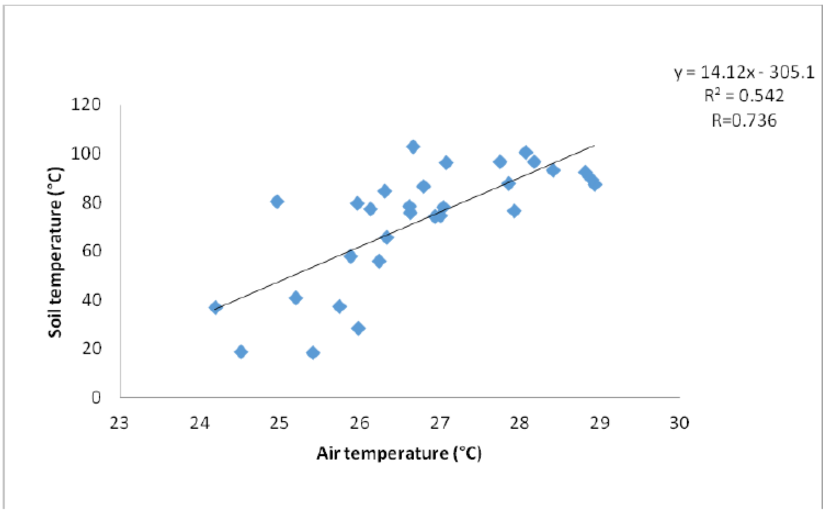

Figure 19: Graph of daily mean soil temperature against daily mean air temperature for June

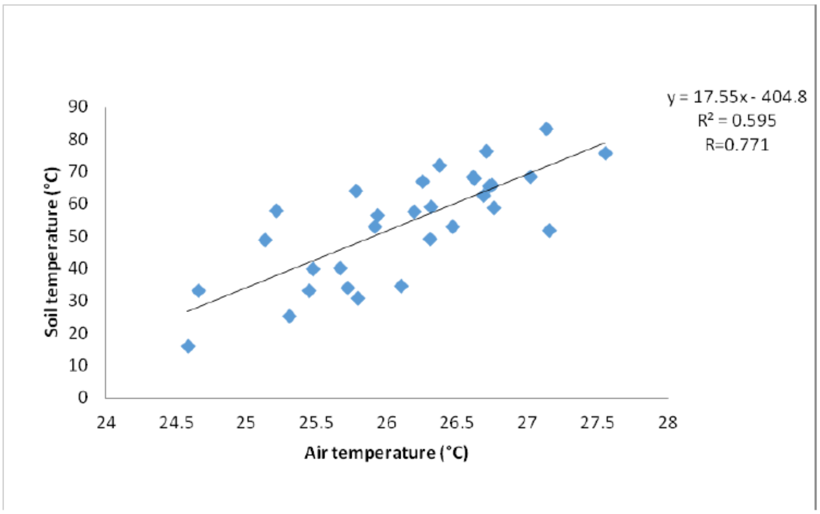

Figure 20: Graph of daily mean soil temperature against daily mean air temperature for July

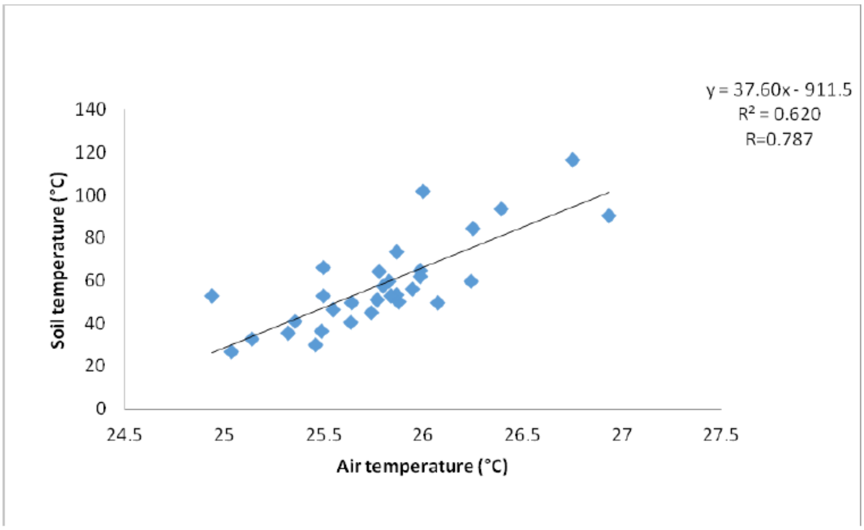

Figure 21: Graph of daily mean soil temperature against daily mean air temperature for August.

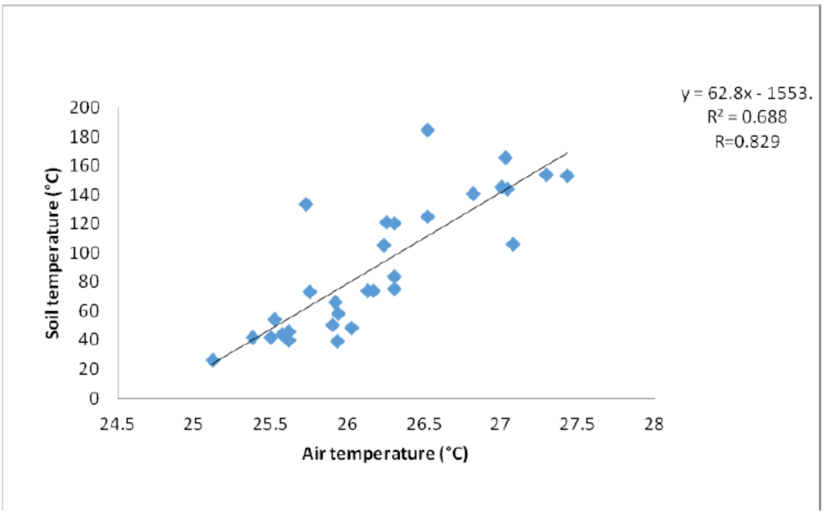

Figure 22: Graph of daily mean soil temperature against daily mean air temperature for September

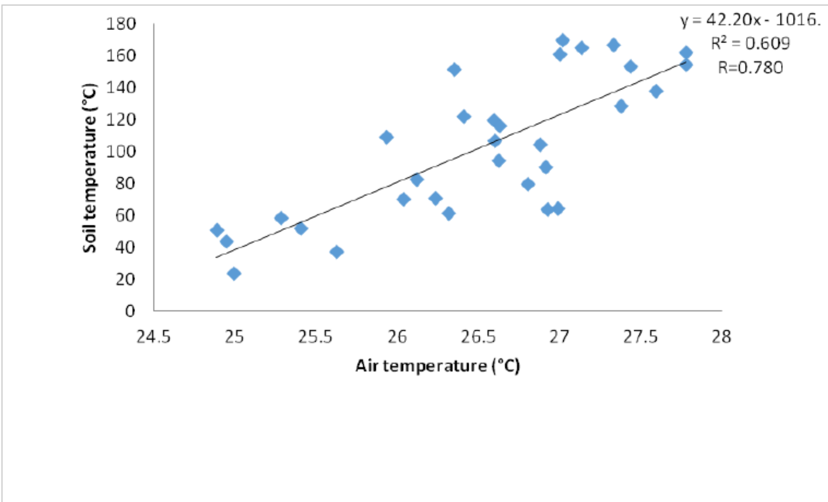

Figure 23: Graph of daily mean soil temperature against daily mean air temperature for October.

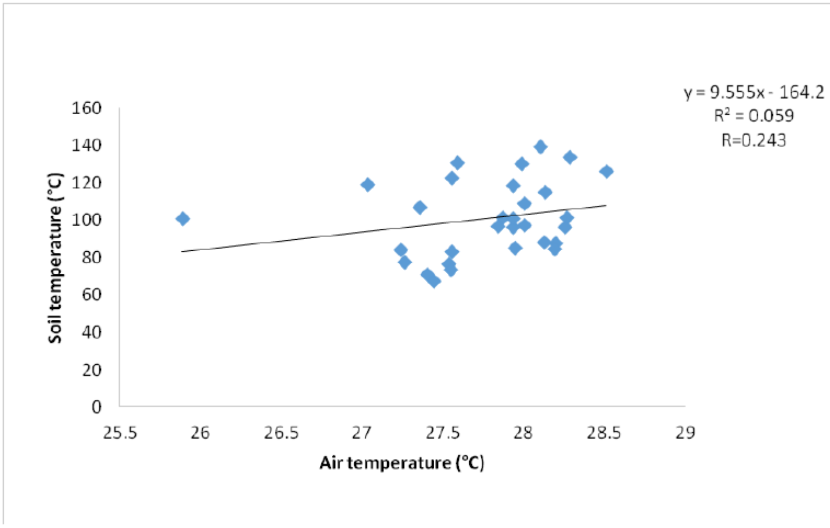

Figure 24: Graph of daily mean soil temperature against daily mean air temperature for November.

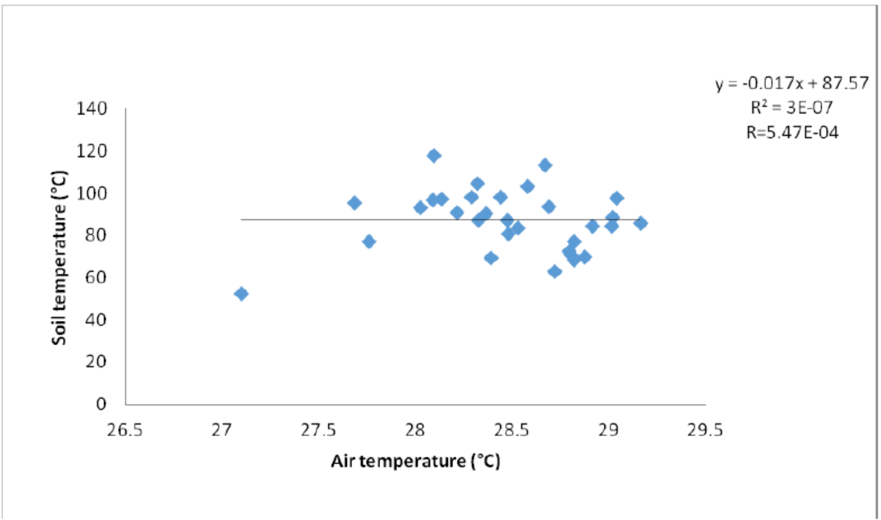

Figure 25: Graph of daily mean soil temperature against daily mean air temperature for December.

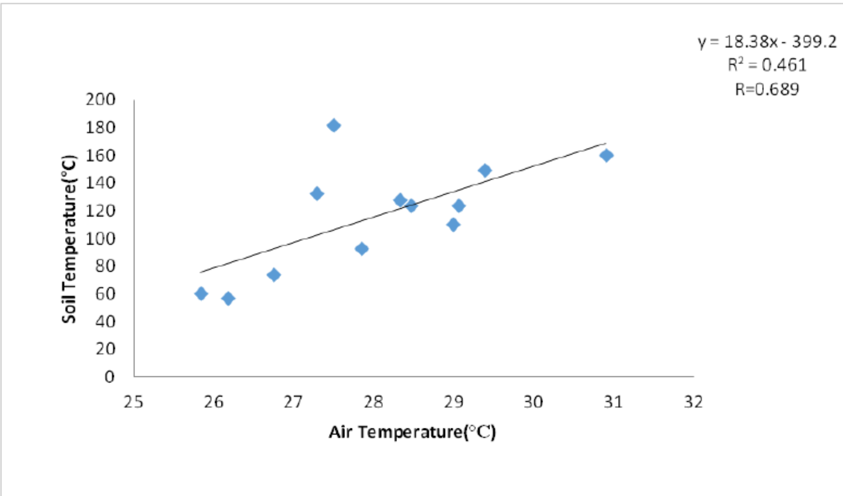

Figure 26: Graph of monthly mean soil temperature against monthly mean air temperature for the year 2009.

IV. Discussion

Figures 1 and 14 show the conditional and unconditional plots respectively for month of January 2009, the correlation coefficients are 0.705 and 0.084 respectively. The difference in the two values was because the errors and unwanted signals present in the unconditional values has been removed, which leads to high correlation coefficient at the conditional value.

Similarly, figures 2 and 15 show the conditional and unconditional plots respectively for month of February 2009, the correlation coefficients were 0.522 and 0.297 respectively. The same goes for the scatter plots from figures 3 and 16 through figures 12 and 25, as the correlation coefficients of the conditional were higher than that of the unconditional value. The reason the same as the one stated for the previous comparisons.

Figure 13 and 26 represents the mean plots for the unconditional and conditional values for year 2009 and the correlation coefficients were 0.722 and 0.689. It must be noted that the mean values for unconditional was very close to values of the conditional, which did not happen in the monthly plots where the correlation varied greatly. This can be traced to the fact that when taking the monthly mean, errors and other unwanted signal values were automatically removed by the calculation process.

V. Conclusion

A significant relationship exists between the average daily air temperature and the observed daily soil temperature at a depth of 10cm and the development of a general model for direct estimation is possible. This study has further buttressed the point that successful predictions of soil temperature with the help of air temperature is viable and if employed in the acquisition of soil temperature data for a given region will lead to minimized sampling time, improve cost effectiveness and reduce maintenance costs. It will also help create a large database of soil temperature which can be localized to specific areas, which will encourage research in various fields.

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