Soil temperature profile and its readiness for controlling buildings indoors Temperature at Erbil city – Iraqi Kurdistan Region (IKR)

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Abstract

Soil temperature varies both diurnally and seasonally and can determine the temperature gradient within the collector loops of the ground source heat pump. To study spatial and temporal variations of soil temperature besides investigating the possibility of using underground soil temperature of the region for the installation of ground heat exchange systems, the current study was conducted. Soil temperature was measured at two locations in Erbil city/ IKR during the period from November, 1st, 2012 to February, 28th, 2013 with temperature sensors inserted in the ground at different depths. . It has been observed that during January and February the soil temperature offered the highest and lowest fluctuations respectively and they were closely related to ambient air temperature. The results also indicated that soil temperature increased with increasing depth up to a depth of 3.5 m in most cases and thereafter started to decrease with increasing depth. Furthermore, it was shown that the reliability of soil temperature prediction from air temperature decreased with the increase in soil depth. Positive differences at a depth of 3.5 m February ranged from 13.73 to 21.56 oC during the winter season from December to. The results can be valuable in planning for preheating system during the cold seasons.

Keywords: Soil Temperature, air temperature, preheating system

1.Introduction

The study of heat flow and thermal properties of various materials, soil in particular, is important because of their applications to our food, shelter and well-being(McIntosh and Sharratt, 2001). It is significant in agriculture, meteorology, biology, civil engineering and heating systems (Possner, 2012). Soil temperatures vary both diurnally and seasonally, the former variation fading out within a few 10s of cm and the latter at greater depth. At a depth of about 15 cm, the temperature is approximately constant and equal to the mean annual air temperature (British Geological Survey, 2011). Due to the extremely high heat capacity of soil relative to air and the thermal insulation provided by vegetation and surface soil layers, seasonal change in soil temperature deep in the ground are much less than and lag significantly behind seasonal changes in overlying air temperature (Reysa, 2012). If the thermal characteristics of the soil are considered constant with depth and time of day, and soil temperature is modeled as a sine wave solution to the heat equation, the amplitude of the diurnal soil temperature wave is expected to decrease exponentially with increasing depth in the soil (McIntosh and Sharratt, 2001). Air temperature correlates well with soil temperature because both are determined by the energy balance at the ground surface (Zheng et al., 1993). Several factors influence the variability of soil temperature in the field (Shumway et al., 1989). Charoenvisal (2008) showed that factors such as slope orientation, terrain, solar radiation, wind, rain, etc can have an influence on thermal behavior of the ground and it is very important to be aware of the extent of the influence and how the affect it. Tillage can affect both the surface micromorphology and the subsurface thermal properties. Change in surface microrelief can greatly influence the local radiation characteristics and the heat balance because of changes in surface orientation and surface slope

(Benjamin et al., 1990). The transfer of heat in the soil at different thermal properties, coupled with radiations and latent heat exchanges at the surface are the primary cause of variations in soil temperature (Hugh and Roger, 2004). Soil temperature and its variations at different depths are unique parameters useful in understanding both surface energy process and regional environmental conditions (Hu and Feng (2002). Unfortunately, few climate stations monitor soil temperature and this parameter is monitored over a limited soil depth in these stations. At a sufficient depth, the ground temperature is always higher than that of the outside air in winter and slower in summer. This difference in temperature can be utilized as a preheating means in winter and pre-cooling in summer by operating an earth heat exchange (Florides and Kalogirou, 2005). Wong et al.(2012) revealed that it is very crucial to measure the soil temperature at different depths and understand its variations. These findings will help the researchers to determine optimum depth of geothermal systems and to obtain a rough guide for sizing the system based on the amount of volume involved for cooling and heating. The current study aimed to study the temporal and spatial variations of soil temperature, soil temperature prediction from air temperature and bench mark the possibility of using of underground temperature for heating and cooling purposes in the region under study.

2.Materials and Methods

The study site is ca 400 m asl and located at $36^{o}\,02^{'}\,05^{''}$ N and $44^{o}\,23^{'}\,02^{''}$ E. Based on 48-year record, the annual precipitation is about 420 mm occurring in a unimodal pattern. It falls between October and May. There is no rainfall during the summer months. Mean annual temperature is about 20 ºC with a maximum temperature of 46 ºC (July) and a minimum of -2 (January). The average annual pan evaporation is about 2500 mm (Kia, 2009). The ground surface was bare, flat and homogeneous. The soil at both locations has a medium texture (loam) with a high proportion of silt.

After excavating a trench of 1 m x 1m x 4.3 m dimensions at both locations, soil cores 5 cm in diameter and 10 cm in length were pushed normally to one face of the trench to obtain three undisturbed samples from depths of 0.5, 1.0, 1.5, 2, 2.5, 3, 3.5 and 4.0 m below the soil following the procedure described by Klute (1986). Additionally, representative disturbed samples were taken from each depth for performing some selected physical and chemical analyses according to procedure outlined by Richards et al.(1954). Table 1 displays the basic physicochemical properties of the studied soils. After that, temperature sensors were installed at each sampling depth, viz., 0.5, 1.0, 1.5, 2, 2.5, 3, 3.5 and 4.0 m below the soil surface. To ensure good contact with the soil the sensors were pushed about 25 cm horizontally into the undisturbed soil face of the trench. The trench was carefully backfilled to its approximate original bulk density and the field was maintained free of vegetation during the measurements. Each sensor (probe) was connected with a special wire of desired length and the other end was kept inside a chamber laid on the soil surface close to the backfilled trench for soil temperature measurement with the recorder. Soil sample were collected for laboratory examination.

The soil temperature was logged twice a day at 3 pm and 3 am by using a compact measuring instrument Model IM testo 925. The period of the study lasted for 4 months between 1st November 2012 and 28 February 2013.

Since the overall trend at both locations was similar, their data wee combined together in most parts of the incoming section.

3.Results and Discussion

3.1.Temporal Variation of Soil Temperature

Figs.1. and 2. display the diurnal variation in soil temperature measured at different depths at 3:00 a.m. and 3:00 p.m. at the studied locations throughout the experimental period from November, 1st, 2012 to February 28sth, 2013 respectively. The diurnal variation at shallow depths is larger than that at greater depths. Similarly, Gao et al. (2008) observed annual and daily fluctuations in soil temperature and attributed the fluctuations to variations in air temperature and solar radiation. The overall seasonal trends in soil temperature at location 1 were similar to those found at location 2.

A closer examination of the time series of the air temperature per se during the study period discloses clearly that it is more strongly subjected to variations or fluctuation than does the soil temperature (Fig.3). Close inspection of Fig.3 elucidated that the ambient temperature decreased with time and then started to increase at about the end of January. This trend was based on plotting the single moving average technique using three observations after checking the stationary of the data using autocorrelation with different lag times.

Tables1 and 3 show the mean, standard deviation and coefficient of variation of soil temperature data measured during the aforementioned period at the different depths for the two locations respectively. One can easily assert from these data at both sites that the coefficient of variation of soil temperature tended to decrease with increase in depth in most cases. This implies that with a few exceptions the 0.5-m and 4-m depths exhibited the highest and lowest coefficient of variation respectively. After reconfiguring the mean values, it can be observed from Fig.4 that the temporal variation of soil temperature decreased with an increase in soil depth. At a depth of 3.5 m and deeper than this depth mean monthly soil temperature remained approximately unchanged irrespective of the time of the year. The temperatures between 3.5 and 4 meters remained relatively constant at about 25-27 °C. As mentioned earlier the insulating effect of the upper strata may be the primary factor responsible for his phenomenon.

A close inspection of Tables and 3 and the time series for soil temperature presented in Figs. 1 and 2 revealed that January and February resulted the highest and lowest fluctuation at a given depth. Comparison of the results presented in Figs.1 and 2 with that presented in Fig.3 revealed that the soil temperature fluctuation at a given depth responded to the ambient temperature closely. It is also evident from Fig.3 that January and February offered the highest and lowest fluctuation in ambient temperature respectively. The main conclusions that can be drawn from the above results are that higher temperature variability was evidently present during cooling than during heating and depth of penetration is somewhat high.

3.2.Variation of Soil Temperature with Depth.

It was observed that the soil temperature at both locations increased with increasing depth up to a depth of 3.5 m in most cases and thereafter started to decrease with increasing depth (Figs. 5 and 6). For the majority of the eight depths studied, the lowest recorded temperature was obtained in November, while the highest recorded temperature was obtained in February. This is the result of the fact that the global solar radiation was at its maximum in November, while the cold winds was at its peak in February.

In general, for the four studied months, the 3.5-m depth was found to be warmer than the other depths because of the highest recorded temperature obtained at this depth for each of the months studied. This contradicts the findings of Chiemeka(2010), who found that the 5-cm depth was warmer than other the 4 depths during the experimental period from December to April. The researcher explained the obtained results on the basis of the fact that the intensity of the incoming solar radiation was always higher at shallow soils (depths) than at deeper soils since the solar radiation got to the 5-cm depth first and heated it up before getting to deeper layers. Apart from this, the authors attributed the obtained results during the current study to the fact that during the summer months which preceded the current study, the soil profiles were heated up to a greater depth and the shallow depths lost most of stored heat during the months of the experiment. The relatively high soil temperature at greater depths during the summer season stemmed from the fact that in the loam soil, there was an easy permeation of radiant heat absorbed from sunlight and air at the soil surface to the bottom (Nwankwo and Ogagarue, 2012). In general, the soil temperature was higher than that of the air during study period. This was in harmony with the findings of NERC (2011). It was found that at times of minimum air temperature, ground temperatures were generally higher and at times of maximum air temperature, ground temperatures were lower. As a rule of thumb, the main reason for the higher soil temperature compared to the mean air temperature is the insulating effect of the upper soil strata.

Furthermore, the results indicated that at both locations, the soil temperature at a given depth during a given month was slightly affected by the time of the day.

3.3.Temperature Differences at Different Soil Depths.

Fig.7 depicts the temperature difference versus depth during November, December, January and February. The value at a given depth, time and month were obtained by averaging the calculated temperature differences of all the days of the month in question for the two study locations. In general, it was clear that the difference tended to increase with depth to a depth of ca 3.5 m and, thereafter, starts to decrease slightly.

The soil temperature differences were greater at 3:00 a.m. than at 3:00 p.m. in most of the studied months. There was an exception for the soil temperature differences at February, which displays greater values at 3:00 pm than 3:00 am. The temperature difference ranged from as low as 1.83 °C at a depth of 0.5 m in November at 3:00 a.m. to as high as 21.56 °C at depth of 3.5 m in December at 3:00 a.m.

Positive differences at a depth of 3.5 m were found during the winter season from December to February and ranged from 13.73 to 21.56 °C. This suggests that they could be used to preheating systems during these times. These differences were higher than those observed by Al-Maliky (2011) for Alkry'at and Alsadr cities in Baghdad at a depth of 4 m. The positive differences were around 7 °C and 10 °C during winter time at the two locations. Evidently, it seems that the underground soils of Erbil city / IKR, are ready for the state-of-the-art ground exchange systems.

3.4.Prediction of Soil Temperature

For this analysis linear regression was employed to predict soil temperature measured at different depths from air temperature and the results are displayed in Table 4 and Fig.4. As it is shown in Table 4. the correlation coefficient between these two variables tended to decrease with increasing depth up to 3 m, beyond which stared to increase then decrease with a reverse sign (negative correlation). Such a relationship between both these two parameters was expected because both of them were determined by the energy balance at the ground surface (Zangana, 2008). Furthermore, it was noticed that the correlation coefficient dropped sharply as the soil depth increased from 0.5 to 1.0 m. For achieving a reasonable degree of prediction accuracy, only the relationship between soil temperature at a depth of 0.5 m and air temperature was considered and the analyses for the remaining depths were discarded (Fig. 8). It is also obvious from Fig.9 that majority of the data points fell on or close to the line 1:1. The linear relationship attributed more than 55% of variation in soil temperature at the indicated depth to variation in air temperature. The results also indicated that the average error of prediction was 2.0 °C (not shown here). Similarly, the researchers, Zheng et al.(1993) have indicated that the error soil temperature prediction varied from 1.5 to 2.9 °C for 19 stations of six climate regions across the United States.

Also, it appears from the obtained results of the current study that the predictive capacity of the model is within the sensitivity bounds of biological response data because study of temperature regulations of microbial processes uses frequently 5 °C temperature increments in incubation assays (Vose and Swank, 1991).

The main outstanding conclusion that can be drawn from the current study is the possibility of using ground temperature for heating purpose in Erbil during the cold seasons.

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مقد درجة حرارة التربة وامكانية استخدامها للسيطرة على درجة الحرارة داخل الابنية فى مدينة اربيل - اقليم كردستان العراق

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المستخلص

تخضع درجة حرارة التربة للتغيرات اليومية والموسمية وهى تحدد الانحدار الحرارى ضمن حلقات انظمة التدفئة . من اجل دراسة التباين الزمانى والحيزى لحرارة التربة فضلا عن امكانية استخدام حرارة باطن الارض لاغراض التدفئة قيست درجة حرارة التربة فى موقعين داخل مدينة اربيل/اقليم كردستان العراق ضمن الفترة المحصورة ما بين شهرى تشرين الثانى 2012 وشباط 2013 باستخدام مجسات حرارية منصوبة على اعماق مختلفة . لوحظ اعلى واقل تذبذب لحرارة التربة خلال شهرى كانون الثانى وشباط على التوالى واستجاب التذبذب الحرارى الى تذبذب حرارة الهواء بصورة وثيقة .

كما اشارت النتائج الى ازدياد حرارة التربة مع ازدياد العمق الى حد 3.5 م وبعدها بدأت بالانخفاض ، و علاوة على ذلك لوحظ بأن دقة التنبؤ بحرارة التربة من حرارة الهواء تقل بأزدياد العمق . كما وان وجود فروقات معنوية موجبة بين حرارة التربة وحرارة الهواء فى المدى ما بين 13.73 و 21.56 م0 عند العمق 3.5 م خلال شهرى كانون الاول وكانون الثانى قد تساعد فى استخدام حرارة باطن الارض لاستخدام التدفئة خلال المواسم الباردة .

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Table 1. Some selected soil physical and chemical properties of the study soil.

Soil depth (m)	Particle size distribution (g kg^{-1})			Textural name	Soil organic content (kg kg^{-1})	Natural water content (kg kg-1)	Bulk density (kg m^{-3})	Porosity $m^3 m^{-3}$	Specific heat capacity (KJ kg^{-1} . $^oK^{-1}$)	Volumetric heat capacity (MJ m^{-3} $^oK^{-1}$)	Weighted volumetric heat Capacity (MJ m^{-3} $^oK^{-1}$)	Thermal conductivity (J s^{-1} m^{-1} $^ok^{-1}$)	Thermal diffusivityivity (cm^2 s^{-1})
	Sand	Silt	Clay										
0.5	290	485	225	Loam	1.6	0.129	1424	0.463	0.8	2.12	1.95	0.261	0.0013
1	282	473	245	Loam	0.7	0.139	1443	0.455	0.76	2.01	1.97	0.255	0.0013
1.5	272	461	267	Loam	0.5	0.158	1458	0.450	0.75	1.99	2.09	0.248	0.0012
2	270	475	255	Loam	0.4	0.176	1493	0.437	0.77	2.04	2.26	0.249	0.0011
2.5	285	472	243	Loam	0.4	0.202	1518	0.427	0.74	1.96	2.40	0.257	0.0011
3	278	463	259	Loam	0.35	0.226	1573	0.406	0.74	1.96	2.59	0.238	0.0009
3.5	271	467	262	Loam	0.34	0.23	1580	0.404	0.75	1.99	2.63	0.245	0.0009
4	282	451	267	Loam	0.3	0.231	1585	0.402	0.73	1.93	2.61	0.247	0.0009

Each value represents the average of two replicates from the two locations

Table 2. Some selected statistical parameters for soil temperature measured at various depths at location 1 during the period from November 1st, 2012 to February 28th, 2013

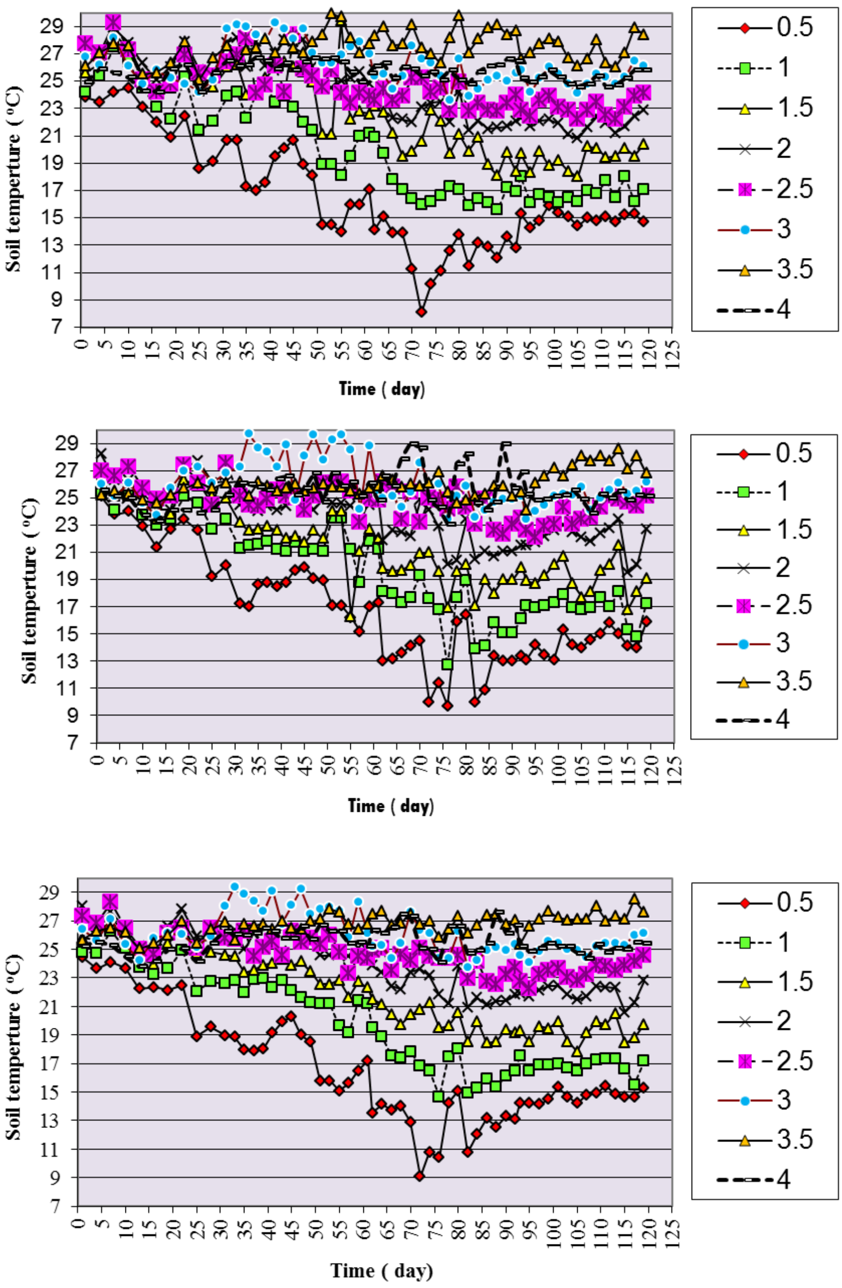
Month	Time	Statistics	Soil Depth (m)							
			0.5	1	1.5	2	2.5	3	3.5	4
November	3:00 AM	Mean	22.21	24.21	25.80	26.81	26.34	25.72	26.56	25.21
		SD	2.07	2.00	1.53	1.25	1.58	1.17	1.00	0.76
		CV	9.34	8.25	5.92	4.66	5.98	4.56	3.75	3.02
	3:00 PM	Mean	22.51	24.05	25.17	26.15	26.22	25.84	25.42	24.41
		SD	1.83	0.96	0.97	1.37	1.13	1.12	0.50	0.76
		CV	8.12	3.97	3.85	5.24	4.30	4.33	1.97	3.10
December	3:00 AM	Mean	17.67	21.91	24.63	26.41	25.39	27.96	27.82	26.19
		SD	2.29	2.15	2.24	1.40	1.52	1.00	0.94	0.50
		CV	12.95	9.82	9.10	5.29	6.01	3.58	3.39	1.91
	3:00 PM	Mean	17.90	21.48	22.16	24.48	25.04	27.89	25.74	25.86
		SD	1.32	1.05	1.74	0.35	0.78	1.74	0.31	0.66
		CV	7.37	4.87	7.84	1.43	3.13	6.24	1.19	2.53
January	3:00 AM	Mean	12.51	17.08	20.56	22.48	23.86	25.39	28.17	25.78
		SD	1.75	1.41	1.57	0.93	0.82	1.04	0.94	0.53
		CV	14.01	8.24	7.64	4.16	3.45	4.11	3.32	2.07
	3:00 PM	Mean	12.84	16.51	19.33	21.93	24.23	25.08	25.69	26.31
		SD	1.99	1.91	1.16	1.38	1.23	1.03	0.64	1.93
		CV	15.52	11.57	6.00	6.27	5.09	4.09	2.48	7.32
February	3:00 AM	Mean	15.00	16.81	19.39	21.87	23.09	25.28	27.25	25.16
		SD	0.42	0.67	0.76	0.57	0.64	0.70	0.92	0.44
		CV	2.82	3.97	3.93	2.63	2.76	2.75	3.37	1.74
	3:00 PM	Mean	14.41	16.93	19.11	22.02	23.83	25.08	27.16	25.04
		SD	0.90	0.89	1.25	1.08	0.98	0.82	1.13	0.41
		CV	6.22	5.28	6.54	4.90	4.13	3.26	4.16	1.63

Table 3. Some selected statistics for soil temperature measured at various depths at location 2 during the period from November 1st, 2012 to February 28th, 2013

Month	**Time**	**Statistics**	**Soil Depth (m)**							
			0.5	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**
November	3:00 AM	Mean	22.38	24.30	25.64	26.80	25.70	26.58	27.43	24.91
		SD	2.14	1.45	1.48	1.02	1.38	0.70	0.89	0.38
		CV	9.54	5.95	5.79	3.79	5.36	2.64	3.26	1.54
	3:00 PM	Mean	22.71	24.51	25.28	26.24	26.27	26.15	25.59	24.61
		SD	1.69	1.37	1.20	1.65	1.22	1.05	0.43	0.36
		CV	7.43	5.60	4.74	6.30	4.64	4.02	1.67	1.48
December	3:00 AM	Mean	17.13	21.03	23.39	25.29	26.49	26.84	27.31	26.25
		SD	2.25	2.00	1.69	1.32	0.94	1.77	0.68	0.46
		CV	13.12	9.52	7.24	5.21	3.55	6.60	2.47	1.75
	3:00 PM	Mean	17.43	20.94	22.47	24.29	25.24	26.34	26.59	25.71
		SD	1.41	1.44	1.02	0.84	0.68	0.90	0.69	0.58
		CV	8.11	6.86	4.54	3.46	2.68	3.42	2.58	2.25
January	3:00 AM	Mean	12.57	16.87	20.19	23.01	24.23	25.69	26.30	25.61
		SD	1.94	1.29	1.53	1.42	1.23	0.64	1.91	1.08
		CV	15.42	7.63	7.57	6.16	5.09	2.48	7.26	4.23
	3:00 PM	Mean	12.87	16.56	19.26	21.91	23.64	25.14	28.16	25.73
		SD	2.00	1.88	1.20	1.40	0.89	1.05	0.94	0.78
		CV	15.53	11.38	6.25	6.37	3.78	4.17	3.34	3.05
February	3:00 AM	Mean	14.89	17.49	19.49	22.31	23.95	25.38	27.36	25.23
		SD	0.98	0.69	1.22	0.87	1.11	0.95	1.07	0.51
		CV	6.55	3.94	6.28	3.88	4.63	3.75	3.93	2.04
	3:00 PM	Mean	14.89	17.49	19.49	22.31	23.95	25.38	27.36	25.23
		SD	0.98	0.69	1.22	0.87	1.11	0.95	1.07	0.51
		CV	6.55	3.94	6.28	3.88	4.63	3.75	3.93	2.04

Table. 4. Values of Pearson correlation coefficients (r) between air temperature and soil temperature measured at different depths.

	Depths below the soil surface (m)							
r	0.5	1	1.5	2	2.5	3	3.5	4
	0.715	0.568	0.439	0.365	0.320	0.001	-0.347	-0.305



`Fig.1.Temporal variation of soil temperature measured at different depths of location 1

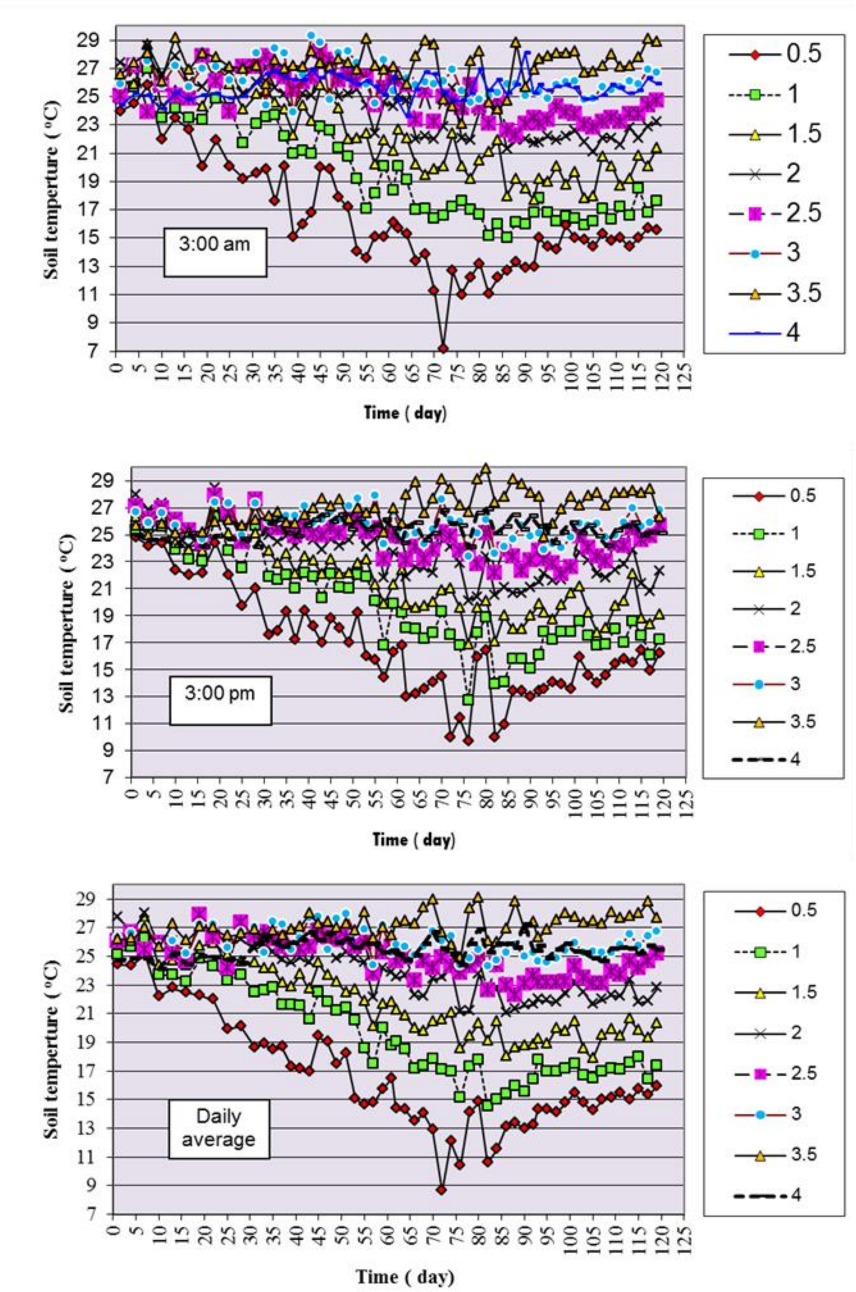


Fig.2.Temporal variation of soil temperature measured at different depths at location 2

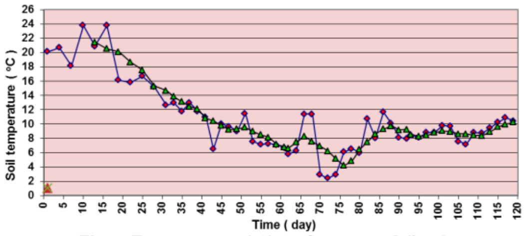


Fig.3. Temporary variation of average daily air temperature recorded at both sites over the period from November 1st, 2012 to Feb 28th, 2013.

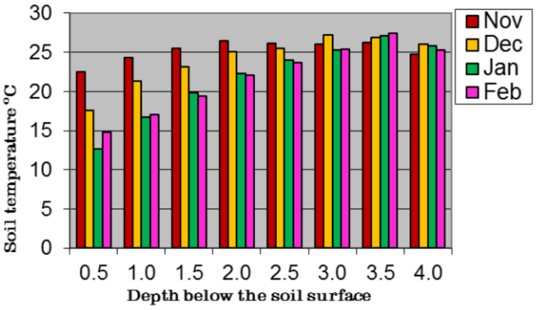


Fig.4. Variation of soil temperature vs months of measurement for different soil depths.

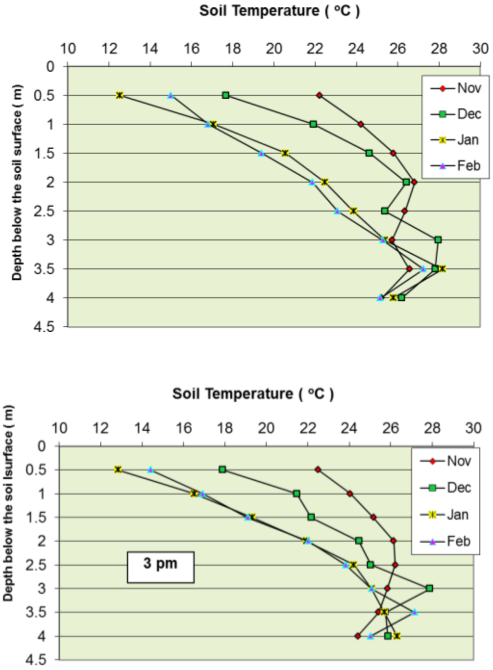


Fig.5. Distribution of soil temperature with depth recorded at 3 am and 3 pm during the period from November 2012 to February 2013 at location 1

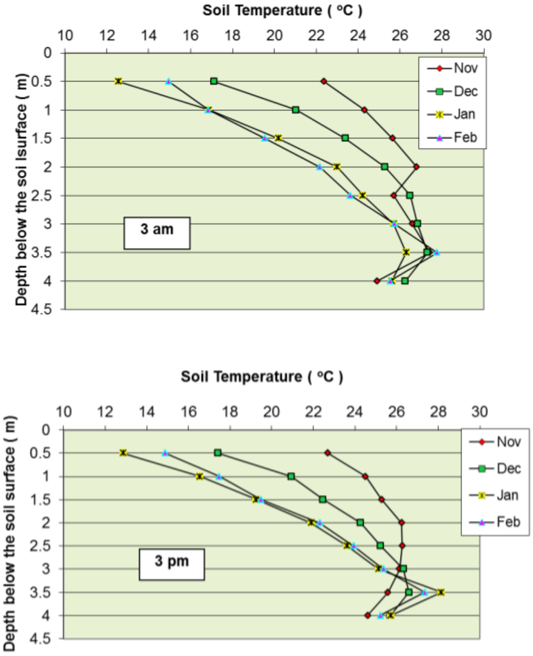


Fig.6. Distribution of soil temperature with depth recorded at 3 am and 3 pm during the period from November 2012 to February 2013 at location 2

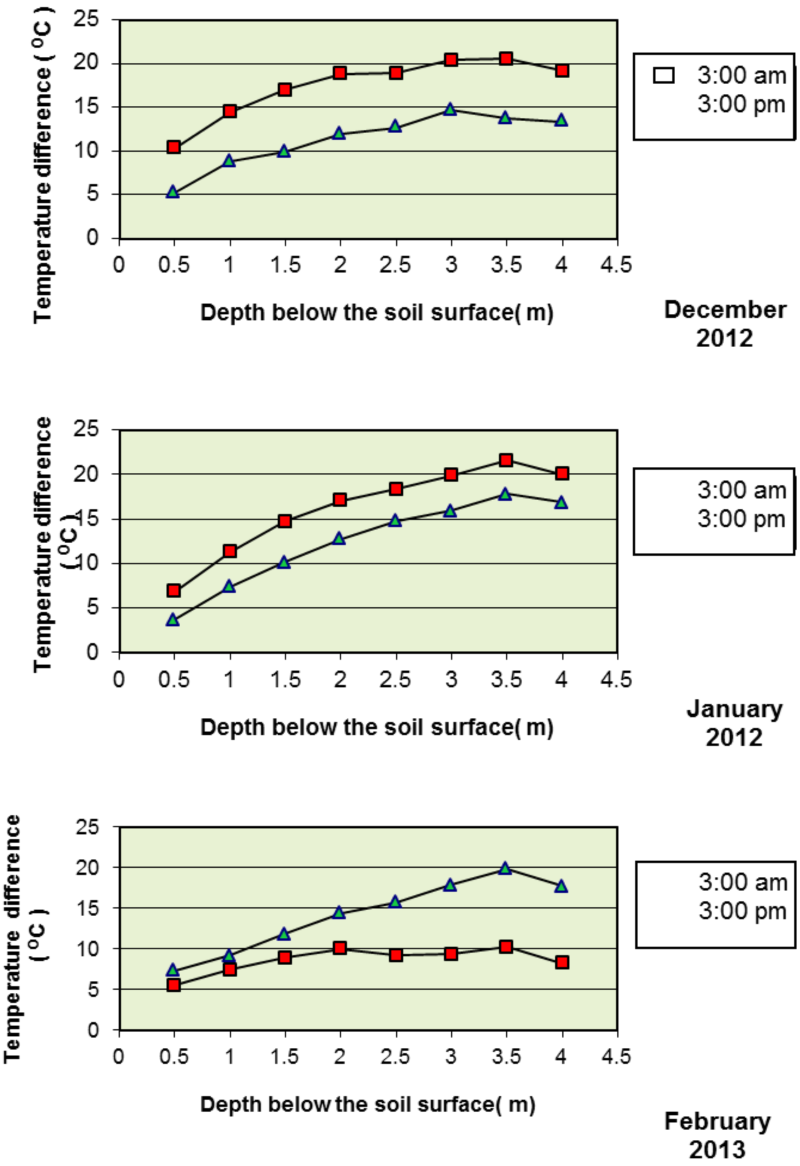


Fig.7. Temperature differences vs. soil depth during the period from November 2012 to February 2013.

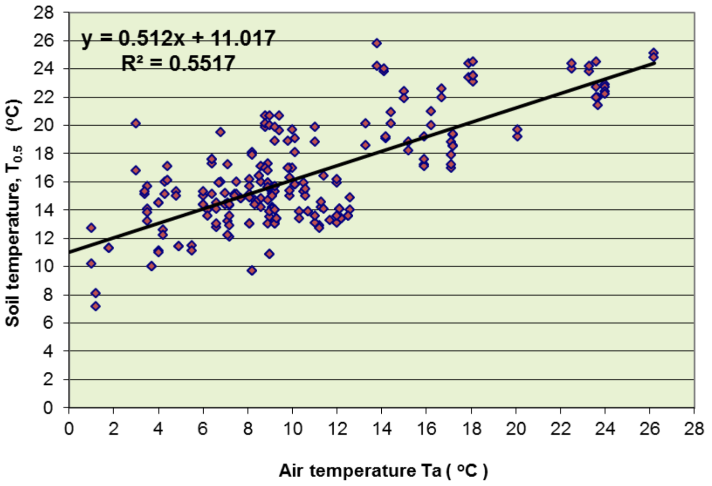


Fig. 8. Prediction of soil temperature at a depth of 0.5 m below the soil surface from air temperatureof the studied site

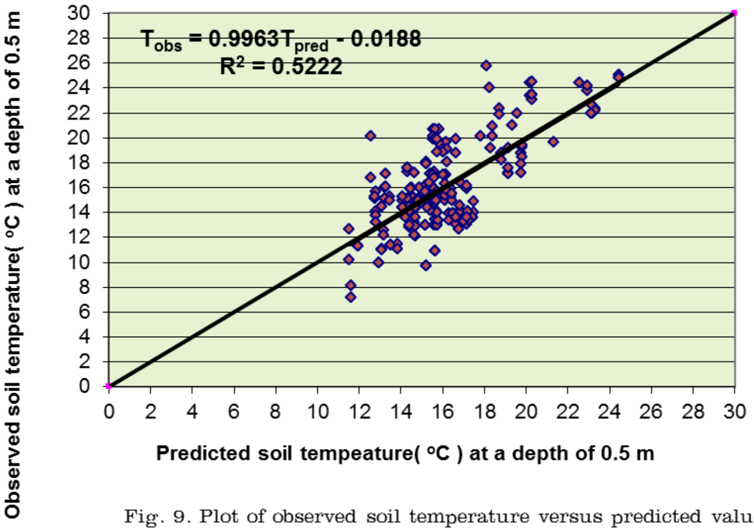


Fig. 9. Plot of observed soil temperature versus predicted values relative to the line 1:1.