Indonesian Journal of Sustainable Agriculture and Environmental Sciences (IJSAES) E-ISSN 3109-1377
Vol. 1 No. 3, 112-119, 2025

Air to Soil Temperature Comparison: A Case Study for Tarnab, Pakistan

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Abstract
Background: The study of air-soil coupling is crucial for agricultural lands such as Tarnab since it provides valuable insights into microbial dynamics, soil ventilation, and the biogeochemical cycle. In addition to this, the floods of 2010 (which also affected the Tarnab) add more value to this work. Governing the air-soil coupling is mandatory for providing the vital oxygen for the roots. **Aim:** In this research, the regression equations linking the seasonal daily average air temperature and seasonal daily average soil temperature have been established for Tarnab. **Methods:** The data of daily maximum/minimum air temperature and soil temperatures (8 am/5 pm), which have been regularly recorded at the Agriculture Research Institute Tarnab from 1996 to 2023, have been used to find the regression. **Results:** The average maximum temperature correlates strongly with 5 pm soil temperature in MAM (R^2=0.4453] and DJF (R^2=0.4995) with 26.75(95% CI: 23.04, 30.77) and 14.28(95% CI: 7.30, 18.83) confidence intervals, respectively and n=28. The R^2 for the SON is fairly strong for the relationship between maximum temperature and 5 pm soil temperature, as well as minimum temperature and soil temperature at 8 am, with values 0.1748 {25.96[95% CI: 20.83, 29.43]} and 0.2872 {19.11[95% CI: 14.78, 22.18]}, respectively. **Conclusion:** Air temperature has shown an influence on soil temperature, besides some irregular behaviour.

Keywords: air-soil coupling; correlation coefficient; regression; soil temperature; Tarnab

Introduction

Air and soil temperatures are crucial meteorological parameters with various applications. Grasping the intricate dynamics of air and soil temperatures, along with their interrelation, will assist in agricultural planning (Ogunjo et al., 2021). Soil temperature fluctuations occur periodically each day, which may be due to variations in energy taking place across the soil's surface. Soil temperature regulates physiochemical and natural processes occurring in the soil and also affects the gas exchange cycles between the atmosphere and soil (Garg et al., 2019). Natural components affect soil temperature by regulating the amount of intensity that is delivered to the soil surface and the extent to which intensity is transmitted from the soil surface down into the profile. It also impacts soil water content, its conductivity, and its availability to plants (Onwuka, 2016). The temperature of the soil regulates the rate at which organic matter decomposes and the mineralization of different organic substances within the soil (Davidson & Janssens, 2006).

Abnormalities in soil temperature likewise influence the growth and output of agricultural crops. For example, during a cool spring season, soil temperature in upper layers hinders corn growth, whereas in a warm spring season, soil temperature contributes to an increase in corn output (Bollero et al., 1996). A huge relationship exists between the day-to-day air temperature and the daily soil temperature at 10 cm profundity (Zheng et al., 1993). Soil temperature is also linked to soil respiration and soil moisture; a significant relationship exists between soil temperature and soil respiration (Tang et al., 2006). Air temperature can be used to determine soil temperature and the exchange of gases between soil and air. Beneficial prediction of soil temperature with the help of air temperature will help reduce time, expenses, and equipment maintenance for essential on-site monitoring and will simplify the process for the researcher to utilize information from alternative sources. Pakistan is an agricultural country; we need to import wheat and furthermore, some sort of cotton.

The per-section yield of land is extremely less. With the adjustment of climatic circumstances and accessibility of water, one unquestionable requirement switches to the climate-appropriate species of crop for drought resistance. As indicated by agro-climatic grouping the 2/3 area of Pakistan is under parched environment (Chaudhry & Rasul, 2004). Air temperature and soil temperature correlate well because both are influenced by the energy level at the ground surface. A 5 cm depth was chosen for soil temperatures on the grounds that most soil environment processes happen inside the top layers of soil (Buringh, 1984). Besides, vegetation can significantly impact the surface energy balance (Ermak, 1992), so it is necessary to adjust the predicted temperatures of the bare soil. Air temperature explains approximately 94% of the variation in soil temperature (Ogunjo et al., 2021). The capacity of soil to conduct heat relies on its thermal properties. Variations in air temperature caused by human actions or climate change directly influence soil temperature, highlighting the importance of examining the relationship between the two.

In this work, we will investigate the coupling of air and soil temperature (1996-2023) with respect to seasons occurring in Tarnab. Thus, highlighting the months for stronger/weaker coupling as well as ideal seasons for growth and harvest.

Methods

Soil temperature and air temperature data of the past 28 years (i.e., from 1996 to 2023) is employed in this problem. The data is recorded at the Agriculture Research Institute (ARI) Tarnab, Peshawar, having a latitude and longitude of 34.011244˚ N and 71.705972˚ E, respectively, with an elevation of 309 m above sea level. The weather of the mentioned site comprises four seasons: DJF (winter); MAM (spring); JJA (summer), and SON (autumn). Air temperature (variable x) from the same station is taken to correlate with soil temperature (variable y). The daily maximum (highest) and minimum (lowest) temperature, as well as soil temperature (at 5 cm depth), are recorded at ARI Tarnab, Peshawar, each day at 8 am and 5 pm local time. This data is then averaged according to the mentioned seasons with a sample size of 28 per model. The relationship coefficients between day-to-day air temperature and day-to-day soil temperature were calculated, involving the R2 value, where the daily pairs exhibit regression. The correlation coefficient is established via linear regression, with atmospheric temperature regarded as the independent variable and soil temperature viewed as the dependent variable. The data is recorded with the help of an analogue thermometer for air temperature and a digital thermometer for soil temperature.

Results and Discussion

Pakistan's climate is extremely diverse with scorching deserts in the south and frozen wasteland in the north. As a result of intense heat, the water balance stays negative in most of the central and southern areas in every season except for the monsoon (Chaudhry & Rasul, 2004). In this context, the temperature of the soil at a depth of 5 cm can be ascertained using the regression equation that was generated by this analytical research. This research will illustrate the extent to which soil temperature and air temperature are interconnected. Furthermore, it will show how to forecast soil temperature within a boundary by utilizing air temperature.

The average values of maximum/minimum air temperature, 8 am/5 pm soil temperature, along with their respective standard deviations (σ) for each season, are shown in Table 1. These values are obtained by taking the mean of all values taken from the period of 1996-2023 for ARI Tarnab.

Table 1. Average maximum, minimum air temperatures and 8 am/5 pm soil temperature

	Average maximum temperature (°C); σ*	Average minimum temperature (°C); σ*	Soil temperature 8 am (°C); σ*	Soil temperature 5 am (°C); σ*
DJF	19.52 (1.15)	2.97 (0.83)	7.26 (1.84)	14.28 (2.01)
MAM	31.11 (1.50)	14.18 (0.83)	19.75 (1.89)	26.76 (2.16)
JJA	37.28 (1.15)	23.41 (0.67)	28.24 (2.11)	33.70 (1.72)
SON	30.36 (0.90)	14.38 (0.81)	19.11 (2.37)	25.97 1.78)

σ* represents the corresponding values of standard deviation in the brackets

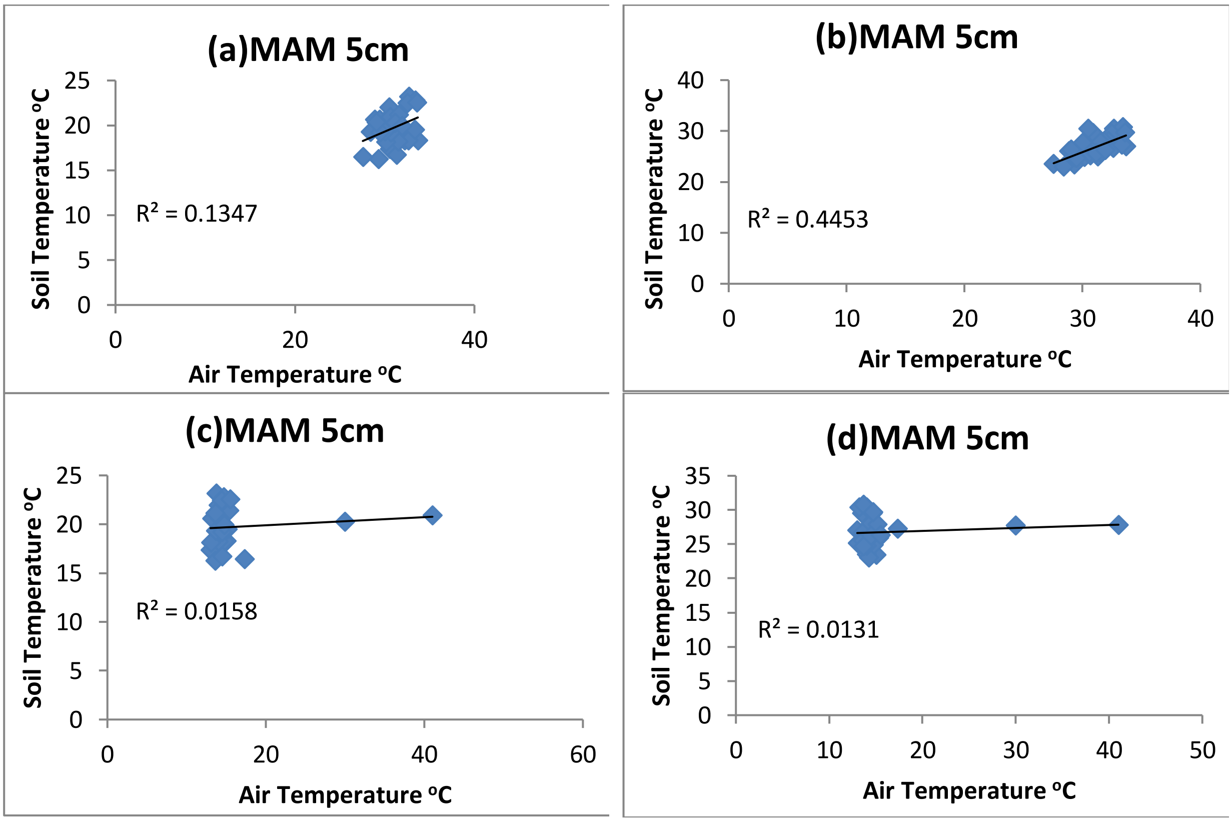

Figure 1. Trend line of air temperature and soil temperature in spring season (5 cm depth), [a. (Max Air temperature, Soil temperature 8 am), b. (Max Air temperature, Soil temperature 5 pm), c. (Min temperature, Soil temperature 8am), d. (Min temperature, Soil temperature 5pm)]

MAM

In MAM, the R^2 correlation between maximum air temperature and 5 pm soil temperature is the highest [*Figure 1 (b)*] with a value of 0.4453. The trend line closely aligns with the data points. This strong connection could be attributed to the fact that April and May are drier months than the other seasons and that dry soil is less resistant to heat than wet soil (Hongbing et al., 2015). The soil is heated at the same time by the insolation received through the crop canopy, if present (wheat is harvested in April and May, leaving the fields immediately exposed to sunlight). It should be emphasized that dry soil has a lower specific heat than wet soil, meaning that heat exchange between the two occurs considerably more quickly.

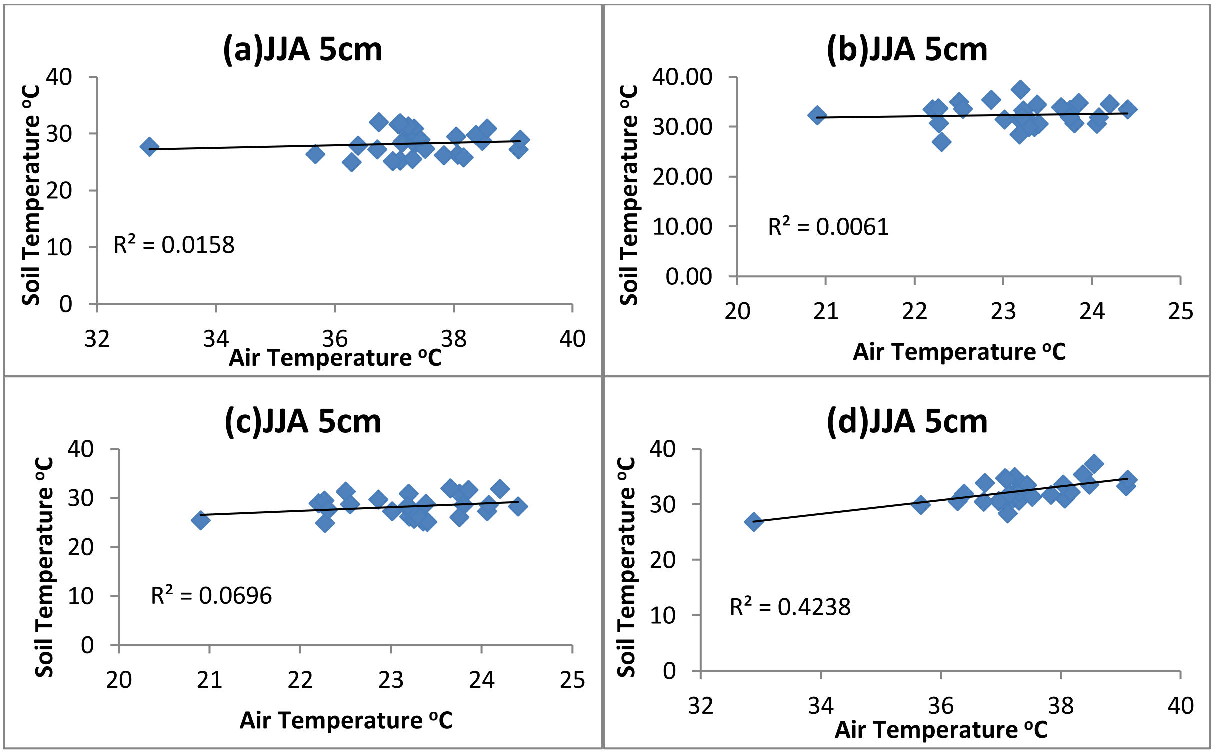

Figure 2. Trend line of air temperature and soil temperature in the summer season (5 cm depth), [a. (Max Air temperature, Soil temperature 8 am), b. (Min Air temperature, Soil temperature 5 pm), c. (Min temperature, Soil temperature 8 am), d. (Max temperature, Soil temperature 5 pm)]

JJA

Air temperature varies quickly in comparison to soil temperature; during the monsoon season, there are times when the air temperature falls abruptly due to cloud formation, but the soil does not react as swiftly. This is the reason R^2 is lower in JJA than that of MAM as illustrated in *Figure 2*. The dispersion in the data in JJA is quite large as compared to other seasons. The effect of the monsoon could be the explanation for the weak association (Ahmad & Rasul, 2008). In this case, the average minimum temperature has a strong value of R^2=0.4238 with 5 pm soil temperature. The monsoon season in Peshawar starts in June/July and lasts until the middle of September. The specific heat of water and air differs, so there is significant temporal and spatial variation in the heat conductivity properties.

SON

The correlation coefficient for the SON is reasonably strong concerning the maximum temperature's relationship with the 5 pm soil temperature (R^2=0.1748) and the minimum temperature and soil temperature at 8 am (R^2=0.2872). After the wet spell of JJA, the dry soil and relatively moderate temperature cause the correlation coefficient to become large in SON (Ahmad & Rasul, 2008) as compared to JJA (*Figure 3*). The assessment of soil temperature is crucial for choosing the appropriate crop variety to cultivate in a specific region. The smallest value of R^2 (0.0007) is obtained for minimum air and 5 pm soil temperature.

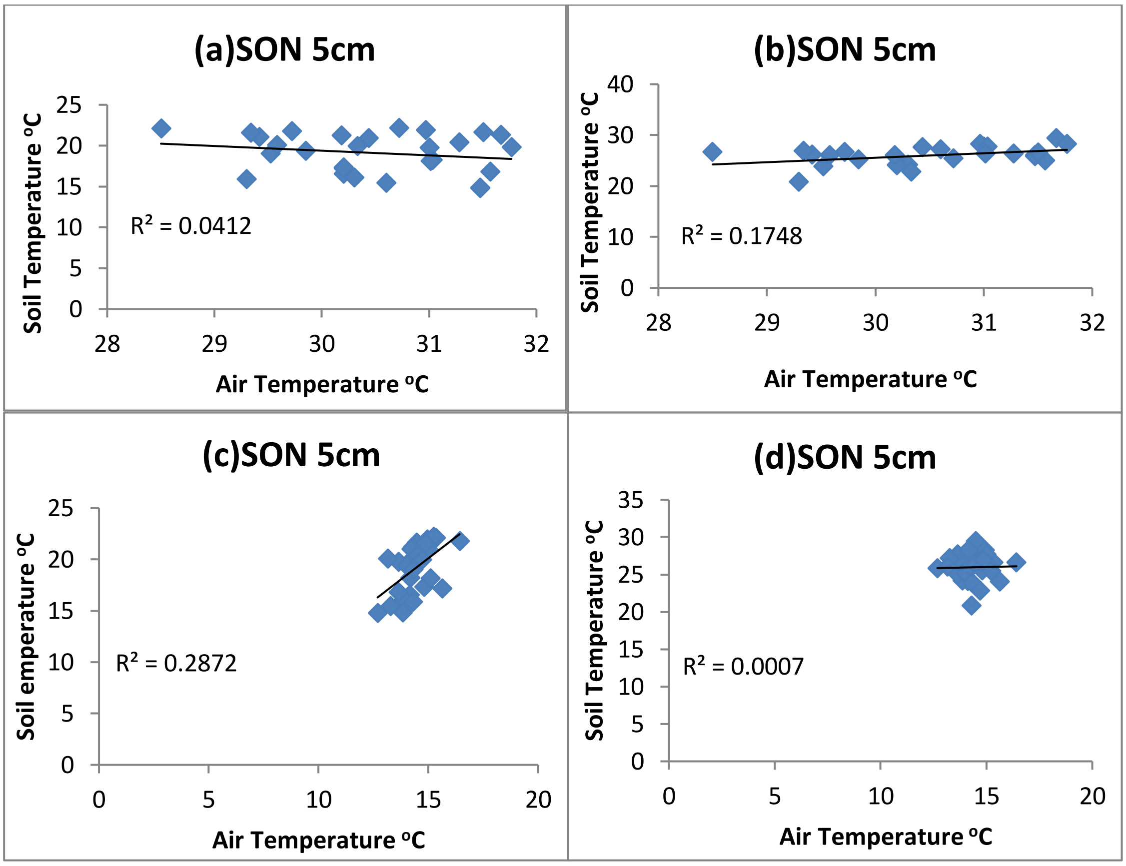

Figure 3. Trend line of air temperature and soil temperature in the autumn season (5 cm depth), [a. (Max Air temperature, Soil temperature 8 am), b. (Max Air temperature, Soil temperature 5 pm), c. (Min temperature, Soil temperature 8 am), d. (Min temperature, Soil temperature 5 pm)]

DJF

In *Figure 4*, the graph shows a significant dispersion in the data, with the exception of Maximum temperature and 5 pm soil temperature, with R^2=0.4995. This considerable dispersion results in a very low value of R^2. DJF is the cultivation time for wheat crops, and this vegetation may hinder soil temperatures from increasing as quickly as air temperatures. Due to this difference, the correlation coefficient R^2 is also quite low. The cause of the significant scatter appears to be the varying moisture levels and canopy coverage across different seasons, which led to variations in thermal conductivity patterns within the same soil. The reason for the lower values of R^2 may also be that in this season, the duration of sunshine hours is less. Winter wheat generally completes its life-cycle most rapidly when grown in low temperatures, but high temperature is required during the later stages of growth (Bobade, 2010). According to a study (Vijaya Kumar et al., 2016), among the phonological stages of wheat, the milk stage was identified as the most sensitive stage and favours high maximum and minimum temperatures, which adversely affect the yield of the wheat crop. In the weather components, maximum temperature was the most sensitive parameter during most of the stages from tillering to maturity, and more significantly affected during jointing to the anthesis stage.

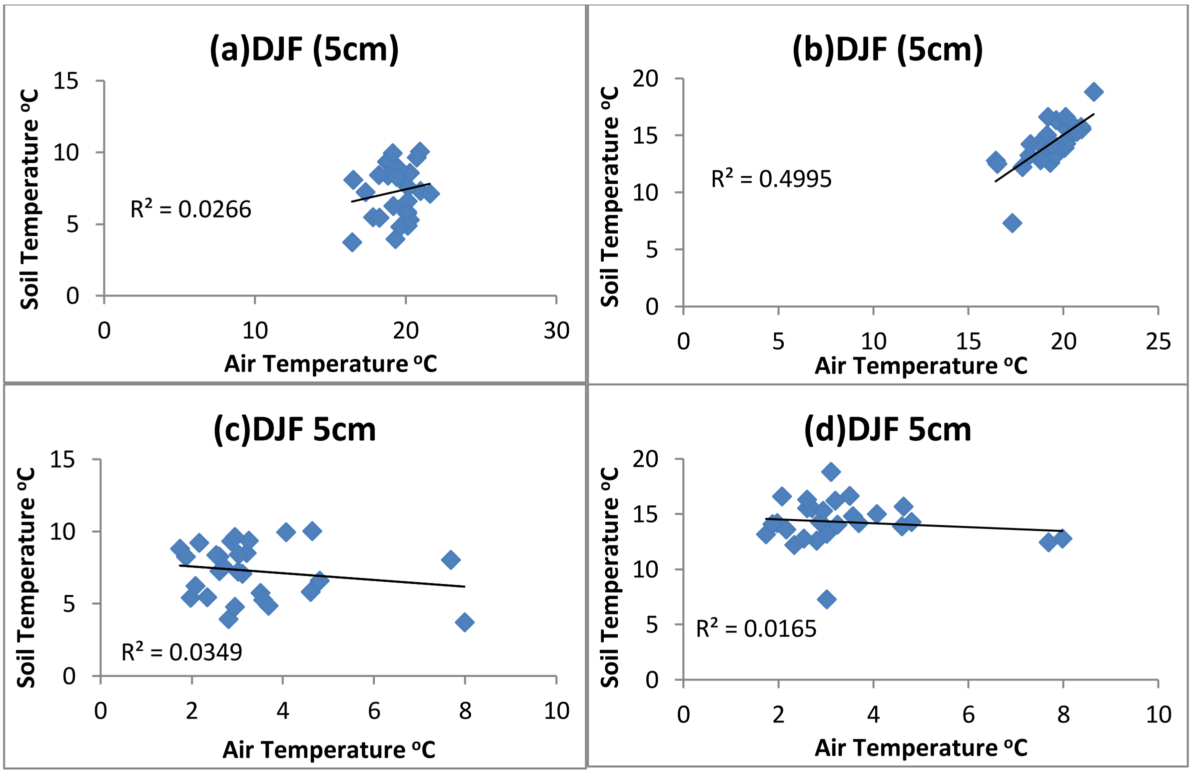

Figure 4. Trend line of air temperature and soil temperature in winter season (5 cm depth), [a. (Max Air temperature, Soil temperature 8 am), b. (Max Air temperature, Soil temperature 5 pm), c. (Min temperature, Soil temperature 8 am), d. (Min temperature, Soil temperature 5 pm)]

Conclusion

Correlation equations are used in this study to attain insights into the fluctuations in soil temperature based on air temperature variations. In the present analysis, DJF (β=1.14±0.31, R^2=0.4995) exhibits the strongest correlation between max air/soil 5 pm temperatures, followed by the MAM (β=0.88±0.26, R^2=0.4453). Whereas, the minimum temperature exhibits fair coupling only in SON (β=1.64±0.60, R^2=0.2872) with 8 am soil temperature. The small values of R^2 between the minimum air/soil 5 pm temperatures, such as in Figure 2b. (β=0.23±0.34, R^2=0.0061), and Figure 3d. (β=0.06±3.39, R^2=0.0007) and others are pertaining to the fact that these correlations are made on the annual average values of each season throughout the period 1996-2023. Nevertheless, this might not be the only reason for such irregularity. Many studies have shown the brutal effect of the 2010 floods on the soil properties of this region, which may have some effect, if not much, on the air-soil coupling.

Acknowledgements

We want to acknowledge the staff of the Meteorology Section (Directorate of Soil and Plant Nutrition), ARI Tarnab, Peshawar, for their contribution in collecting data. Authors Amna Shafi and Aamir Khan have equal contributions in the conception, ideas, calculations and plotting.

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