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Soil temperature variations between a Typic Fragiudults and a Typic Paleudults in the Ozark Highlands of Missouri[1,2]

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ABSTRACT

Soil temperature measurements from a Soil Climate Analysis Network (SCAN) monitoring site in the Ozark Highlands Major Land Resource Area (MLRA 116A) were evaluated on landscapes comprising *Typic Fragiudults* (Scholten series) and *Typic Paleudults* (Poynor series). The five soil forming factors were similar for both soils, with the major difference between the adjacent soils being a fragipan in the Scholten series. Air and soil temperatures were collected from a weather station of the USDA-Natural Resources Conservation Service near the border of the mesic soil temperature regime and udic soil moisture regime zone. The mean annual soil temperature observed in the Scholten soil (13.5° C) was 0.5° C cooler than the mean annual soil temperature in the Poynor soil (14.0° C). This study showed little difference in mean soil temperatures between soil types from January to April and from August to December. During the months of May, June and July, the Poynor mean soil temperature was higher (by 1.1° C, 1.4° C and 1.2° C, respectively) than the Scholten mean soil temperature.

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According to this study, it is possible that the mean annual soil temperature of fragipan soils is cooler than adjacent soils with no fragipan properties. The greatest differences between mean soil temperature and mean air temperature were observed during the months of November (5.1° C for Scholten soil and 5.3° C for Poynor soil); December (5.0° C for Scholten soil and 4.9° C for Poynor soil); and January (4.5° C for Scholten soil and 4.4° C for Poynor soil). The smallest difference was during the month of March (0° C for Scholten soil and 0.3° C for Poynor soil). This study also indicated that the mean annual soil temperature in the Ozark Highlands can vary by soil series depending on soil properties affecting heat transfer within pedons.

Key words: soil temperature, soil temperature regime, fragipan soils

RESUMEN

Variaciones de temperatura del suelo entre un *Typic Fragiudults* y un *Typic Paleudults* en las tierras altas del Ozark de Missouri

Se evaluaron mediciones de temperatura de suelo de la red de monitoreo de clima (SCAN, por sus siglas en inglés) en el área principal de recurso de terreno en las tierras altas del Ozark (MLRA 116A), en un paisaje compuesto por un *Typic Fragiudults* (serie Scholten) y un *Typic Paleudults* (serie Poynor). Los cinco factores de formación de suelos se mantuvieron constantes para ambos suelos. La mayor diferencia entre los suelos adyacentes es la presencia del fragipan en el suelo Scholten. Se calculó la diferencia entre las medias de temperatura del suelo. Se obtuvieron los datos de temperatura de aire y del suelo de la estación meteorológica del Servicio de Conservación de Recursos Naturales del Departamento de Agricultura de Estados Unidos cerca de la zona límite del régimen de suelo mésico y el régimen de humedad de suelo údico. La media anual de temperatura en el suelo Scholten (13.5° C) fue 0.5° C más fría que la media anual de temperatura en el suelo Poynor (14.0° C). Este estudio no mostró diferencias en las medias de temperatura del suelo entre los tipos de suelo en los meses de enero a abril y agosto a diciembre. Durante los meses de mayo, junio y julio la media de temperatura del suelo en el suelo Poynor fue más alta (por 1.1° C, 1.4° C y 1.2° C, respectivamente) que la media de temperatura del suelo en el suelo Scholten. De acuerdo con este estudio es posible que la media anual de la temperatura en suelos con fragipan sea más fría que las de los suelos adyacentes sin fragipan. Las mayores diferencias entre la media de la temperatura del suelo y la media de la temperatura del aire se observaron durante los meses de noviembre (5.1° C para el suelo Scholten y 5.3° C para el suelo Poynor); diciembre (5.0° C para el suelo Scholten y 4.9° C para el suelo Poynor); y enero (4.5° C para el suelo Scholten y 4.4° C para el suelo Poynor). La menor diferencia se observó durante el mes de marzo (0° C para el suelo Scholten y 0.3° C para el suelo Poynor). Este estudio también indica que la temperatura media anual del suelo en las tierras altas del Ozark puede variar según las series de suelo, dependiendo de las propiedades del suelo que afectan la transferencia de calor dentro de los pedones.

Palabras clave: temperatura del suelo, regímenes de temperatura del suelo, suelos con fragipan

INTRODUCTION

Soil temperature can be estimated from air temperature (Soil Survey Staff, 1999) and from the average of four readings equally spaced throughout the year, at about 50-cm or greater depth (Soil Survey Staff, 1999; 2014). In most of the United States, 1° C is added to the mean annual air temperature to estimate the mean annual soil temperature (Buol et al., 1997). Soil temperature influences biological, chemical and physical processes that influence soil genesis and, in turn, soil properties and plant growth (Onwuka and Mang, 2018). Processes such as bioactivity, organic matter accumulation and decomposition, cation exchange capacity (CEC), availability of nutrients, pH, soil structure, aggregate stability, soil moisture content, and soil aeration are influenced by soil temperature. Soil temperature influences water uptake, nutrient uptake and root growth. Therefore, soil temperature has implications for soil genesis as well as for the use and management of the soil for crop production (Comerma and Sánchez, 1981; Onwuka and Mang, 2018).

The influence of soil temperature on soil genesis and soil properties is emphasized by the recognition of nine soil temperature regimes in Soil Taxonomy (Soil Survey Staff, 1999; 2014). This study focuses on the mean annual soil temperature (MAST) for the mesic soil temperature regime (8° C to < 15° C) and for the thermic soil temperature regime (> 15° C to 22° C).

The fragipan is a hardpan that limits root penetration and water movement through the soil profile (Soil Survey Staff, 1999; 2014). Fragipans occur in 12% of the land area in the U.S., distributed among 28 states and comprising four soil orders (Alfisols, Ultisols, Inceptisols and Spodosols). The presence of fragipan in the Ozarks region was recognized by Krusekopf (1942). The distribution of soils with fragipans in Missouri covers 1.7 million hectares (24% of the land area) (Bockheim and Hartemink, 2013). These authors analyzed 36 case studies of fragipan presence, but the Scholten series was not among them.

Data from the Soil Climate Analysis Network (SCAN) provided an opportunity to compare soil temperature in a soil with a fragipan to a soil without a fragipan where the five soil forming factors were similar for both soils. The objective of this work was to evaluate soil temperature variations between a pedon classified as a *Typic Fragiudults* and an adjacent pedon classified as a *Typic Paleudults* in the Ozark Highlands Major Land Resource Area (MLRA 116A) (USDA-NRCS, 2006) of Missouri. Soil temperature measurements from a climate-monitoring network in Missouri were collected for a period of seven years. The results were used to verify and update taxonomic classification, provide a more precise soil temperature estimate for the Ozark Highlands, and provide reference data for future research in soils with fragipans.

MATERIALS AND METHODS

Soil temperature was evaluated using an automated SCAN weather station with one set of sensors per pedon installed in July 2012. This station provides hourly data on air, soil temperature and volumetric soil water content. The temperature and volumetric water content measurements were made on the Scholten and Poynor soil series in soil profiles that were adjacent to each other on the backslope position of a rolling hills landscape (Figure 1). The Scholten pedon (*Loamy-skeletal, siliceous, active, mesic Typic Fragiudults*) was on the upper backslope and the Poynor pedon (*Loamy-skeletal, over clayey, siliceous, semiactive, mesic Typic Paleudults*), on the lower backslope. The two pedons were approximately 2 m apart. The station is in Douglas County, Missouri, at 36° 59' 50.5" N; 92° 15' 33.9" W and 337 m above sea level (Figures 2 and 3). This site is representative of the mesic soil temperature regime. Bockheim and Hartemink (2013) reported that 60% of the soil series with fragipans in the USA have a mesic soil temperature regime. Table 1 summarizes the instrumentation and configuration of the station.

The data were collected over a seven-year period (August 2012 to December 2019). The HygroClip[7] air temperature sensors were calibrated annually with an environmental chamber to a ± 2° C precision range. The Hydraprobe soil temperature and soil moisture sensors were calibrated by the manufacturer before installation. The CS107 thermistors were installed adjacent to the soil temperature sensors to validate the soil temperature data. The data were automatically validated against limits and flagged if a value was outside the preset limits. Any flagged value was examined to determine accuracy, and the appropriate corrections were made. Volumetric water content was measured by Hydraprobe and is reported as m^3/m^3.

The data were graphed, and comparisons were made among sensors to verify that the data were within an acceptable range. Soil temperature readings that were determined to be unreasonable were removed from the data set and the sensor was replaced. Routine maintenance of the stations was performed to verify the status of batteries and sensors. Close communication was maintained with the National Water and Climate Center to detect potential irregularities in data collection. Data were summarized using InfoStat version 2008 to determine

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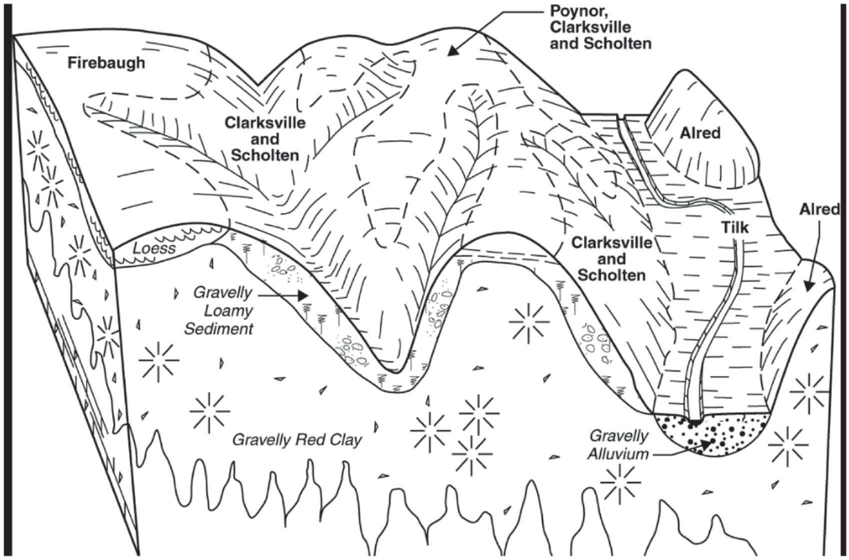

FIGURE 1. Typical pattern of soils and parent material of the Poynor-Scholten series (Benham and Daniel Childress, 2005).

mean, standard deviation, coefficient of variation, variance and standard error (Di Rienzo et al., 2008).

Scholten Soils

The Scholten series consists of very deep, moderately well drained soils that have a fragipan and are found at the upper shoulders of hillslopes (Figure 4). These soils formed in colluvium and the underlying residuum weathered from cherty limestone (Soil Survey Staff, 2021a). In a study on the Scholten series, Aide et al. (2006) observed that upper and lower boundaries of the fragipan correspond to lithologic discontinuities separating loess and bioturbated residuum from the underlying dolomite. Clay illuviation was observed in the fragipan, inferring that weathered soil material from the upper sequum impacted fragipan expression. The study also suggested that the Scholten soils showed no evidence that the Si-cementing agents were associated with the fragipan formation.

In this study, the particle-size control section of the Scholten pedon averaged 16% clay and 37% coarse fragments. Table 2 provides a summary of soil properties collected during the soil profile description and the laboratory characterization. Figure 4 shows horizon depths and labels. The fragipan in this profile occurs from 38 to 67 cm and has a coarse fragments content of 60 to 64%. The Scholten series is a bench-

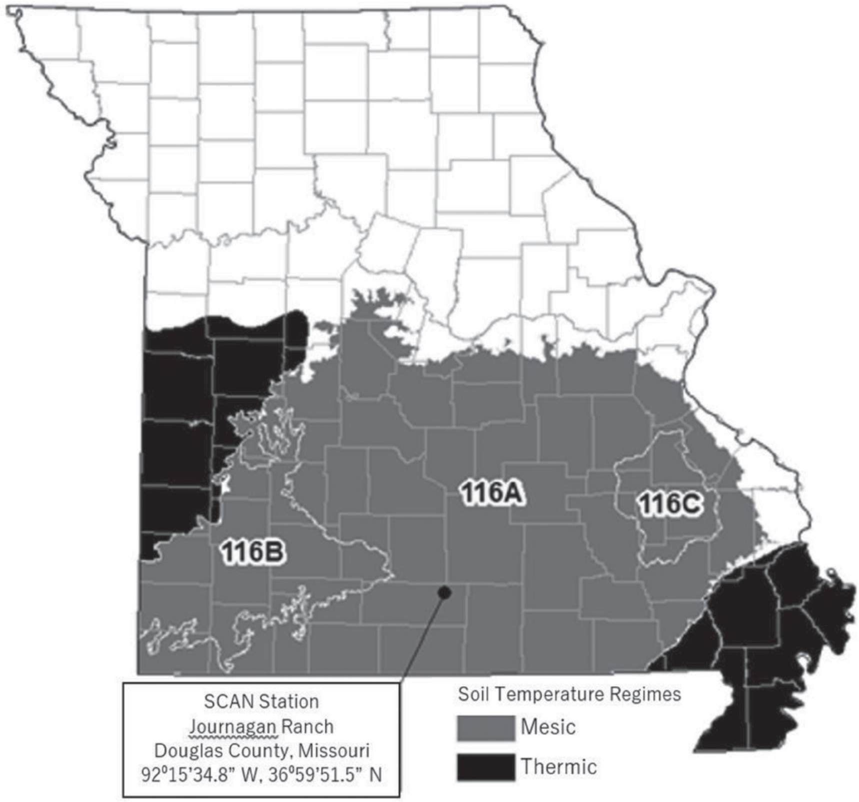

FIGURE 2. Location of the Journagan Ranch SCAN site, Douglas County, MO, in relation to Major Land Resource Areas (MLRAs) and Soil Temperature Regimes.

mark soil for the Ozark Highlands MLRA and has been correlated in 32 counties in southern Missouri. This soil series covers an area of 284,267 ha, equivalent to 3.3% of the MLRA (Soil Survey Staff, 2021b) (USDA-NRCS, 2006).

Poynor Soils

The Poynor series does not contain a fragipan or fragic features (Figure 5). This soil consists of very deep, well-drained, moderately permeable soils on hillslopes. They formed in gravelly colluvium weathered from dolomite or limestone and the underlying clayey residuum weathered from shale (Soil Survey Staff, 2021c). In the sampled pedon, the particle-size control section of this soil averaged 44% clay and 37% coarse fragments. Table 3 provides a summary of soil properties collected during the soil profile description and the laboratory character-

FIGURE 3. Journagan Ranch SCAN site in Douglas County, Missouri.

ization. The Poynor series is a benchmark soil for the Ozark Highlands MLRA and has been correlated in 29 counties in southern Missouri and Smyth County, Virginia. This soil series covers an area of 374,826 ha, equivalent to 4.4% of the MLRA, and 1,741 ha of the Southern Appalachian Ridges and Valleys MLRA or equivalent to 0.03% of the MLRA (Soil Survey Staff, 2021b) (USDA-NRCS, 2006).

RESULTS AND DISCUSSION

Air temperature versus soil temperature

The mean annual air temperature for the evaluated period was 12.6° C and the mean annual precipitation was 1,352 mm. The mean monthly minimum air temperature (0.0° C) occurred in January and the mean monthly maximum air temperature (23.7° C) occurred in July (Table 4). For both soils, mean monthly soil temperatures generally followed a similar trend as air temperature although the maximum soil temperature occurred in August, one month later than for air temperature (Figures 6 and 7).

TABLE 1.—*Missouri Soil Climate Analysis Network configuration (Schaefer et al., 2007).*

Parameter	Description
Precipitation (inches)	TB4 Tipping bucket precipitation gauge at 3 m above the ground.
Air Temperature (ºC) / Relative Humidity (%)	HygroClip sensor at 1.6 m above the ground.
Wind Speed (mph) and Direction	RM Young sensor at 3 m above the ground.
Solar Radiation (W/m²)	LI-COR 200 pyranometer at 3 m above the ground.
Volumetric Soil Water (Volts)	Hydraprobe Digital Sdi-12 (2.5 Volts) soil moisture sensors at 5, 10, 20, 50 and 100 cm with the exception of Scholten site where the sensors were at 5, 10, 20, and 50 cm.
Soil Temperature	Hydraprobe Analog (2.5 Volts) soil temperature sensors at 5, 10, 20, 50 and 100 cm with the exception of the Scholten site where the sensors were at 5, 10, 20 and 50 cm.
Data Transmission	RV 50 modem.

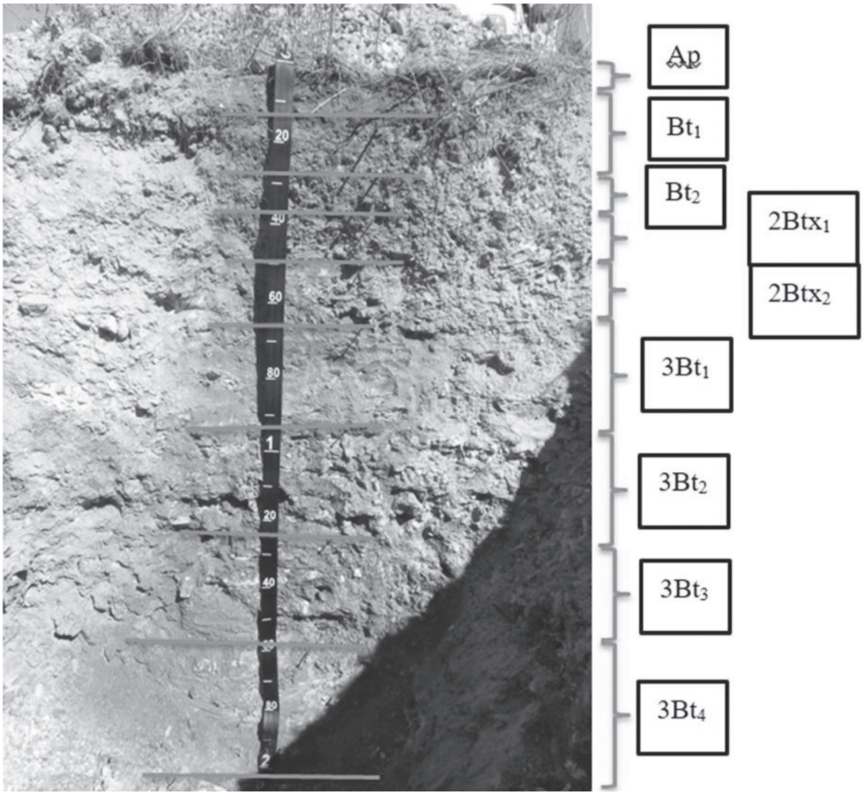

FIGURE 4. Horizon depths and designations of the Scholten soil profile.

Soil temperatures were generally warmer than air temperature during the winter months (December, January, February) and cooler than air temperature during the summer months (June, July, August). Temperatures near the soil surface generally followed air temperature much more closely than at deeper horizons (Figures 6 and 7). During the month of January, the mean soil temperature at 5 and 10 cm was lower than the mean soil temperature at 20 and 50 cm depth. During the months of May, June, July and October, the mean soil temperature at 5 and 10 cm was higher than at the 50 cm depth. The opposite occurred during the months of November and December. Mean monthly soil temperature was approximately the same as air temperatures in March and September. The soil temperature data supports labeling this area as a mesic soil temperature regime.

Soil temperature for classification is determined at 50-cm depth where diurnal fluctuations no longer occur (Buol et al., 1997). As a gen-

TABLE 2.—*Soil profile description summary for the Scholten pedon.*

Scholten series soil profile							
Horizon	Depth (cm)	Matrix colors (moist)	Texture	Coarse fragments > 2 mm (%)	Clay content (%)	Structure	pH (H2O, 1:1)
Ap	0 to 13	10YR 4/3	silt loam	29	11.3	weak fine subangular blocky	6.0
Bt_1	13 to 28	10YR 5/6	silt loam	29	14.2	moderate medium subangular blocky	5.9
Bt_2	28 to 38	10YR 5/6	silt loam	53	20.0	moderate fine subangular blocky	5.7
$2Btx_1$	38 to 50	7.5YR 5/4	silt loam	60	22.7	moderate very fine subangular blocky	5.1
$2Btx_2$	50 to 67	10YR 6/4 (80%) and 2.5YR 4/6 (20%)	silt loam	64	20.2	moderate very fine subangular blocky	4.8
$3Bt_1$	67 to 95	2.5YR 4/6	silt loam	17	13.1	strong fine subangular blocky	4.7
$3Bt_2$	95 to 125	10YR 7/6	clay	57	64.2	moderate fine subangular blocky	4.7
$3Bt_3$	125 to 160	10YR 7/6	clay	40	56.0	moderate medium subangular blocky	4.7
$3Bt_4$	160 to 203	10YR 7/6	clay	26	69.7	moderate medium subangular blocky	4.6

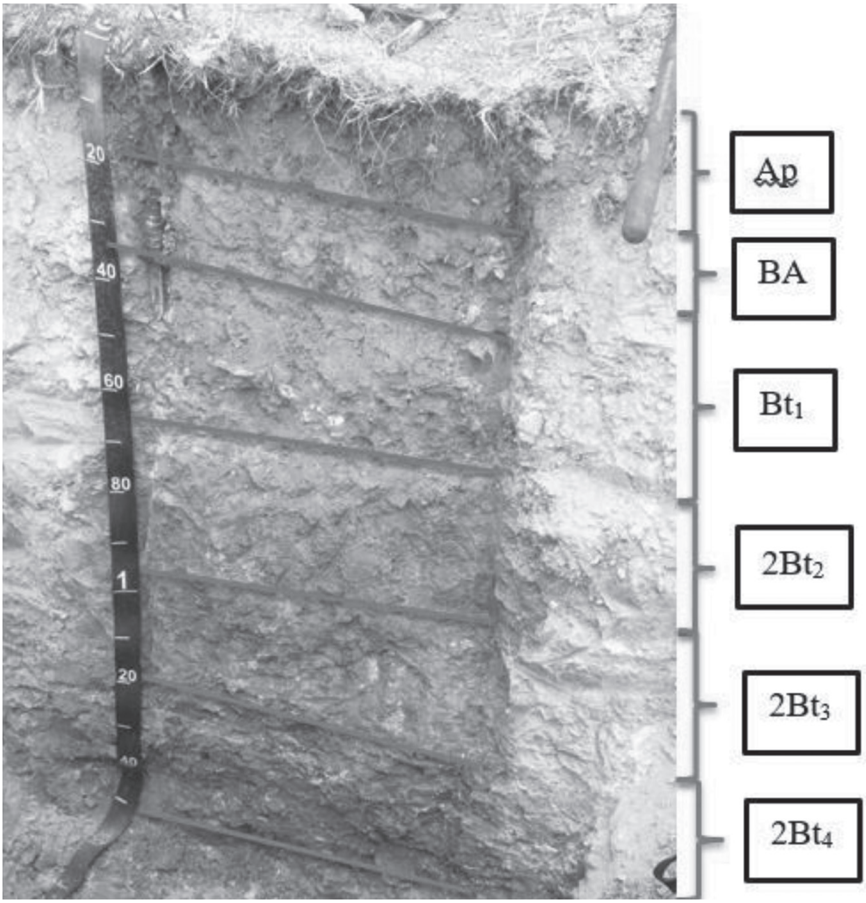

FIGURE 5. Horizon depths and designations of the Poynor soil profile.

eral observation, the mean annual soil temperature at 50 cm can be estimated by adding 1.0° C to the mean annual temperature (Buol et al., 1997). At this site the mean annual soil temperature for the Scholten pedon can be estimated by adding 0.9° C to the mean annual air temperature (Table 4). However, for the Poynor pedon, mean annual soil temperature at 50 cm is estimated by adding 1.4° C to the mean annual air temperature (Table 4) demonstrating that the Scholten pedon was cooler than the Poynor pedon and most of the deviation between air temperature and soil temperature occurred during the early and mid-growing seasons at these sites.

During the months of May, June, and July, the Scholten pedon mean soil temperature at 50 cm was cooler (by 1.1° C, 1.4° C and 1.2°

TABLE 3.—*Soil profile description summary for the Poynor pedon.*

Poynor series soil profile							
Horizon	Depth (cm)	Matrix colors (moist)	Texture	Coarse fragments > 2 mm (%)	Clay content (%)	Structure	pH (H2O, 1:1)
Ap	0 to 20	10YR 4/3	silt loam	38	10.3	weak fine subangular blocky	6.1
BA	20 to 35	10YR 5/4	silty clay	56	54.3	moderate fine subangular blocky	6.4
Bt_1	35 to 66	7.5YR 5/4	silty clay loam	43	30.3	moderate fine subangular blocky	5.6
$2Bt_2$	66 to 98	2.5YR 4/6	clay	9	58.3	moderate medium angular blocky	5.0
$2Bt_3$	98 to 124	2.5YR 4/6	clay	37	56.0	moderate medium subangular blocky	4.7
$2Bt_4$	124 to 203	2.5YR 4/6	clay	65	67.0	moderate medium subangular blocky	4.7

TABLE 4.—*Difference between mean monthly soil temperature and air temperature for the Scholten and Poynor pedons at the Journagan Ranch SCAN site.*

Month	Mean Monthly Air Temp. Journagan Ranch (°C)	Mean Monthly Soil Temp. at 50 cm (°C)	Temperature Difference [Soil Temp. at 50 cm - Air Temp.] (°C)	Mean Monthly Soil Water Content (m^3/m^3)	Mean Monthly Soil Temp. at 50 cm (°C)	Temperature Difference [Soil Temp. at 50 cm – Air Temp.] (°C)	Mean Monthly Soil Water Content (m^3/m^3)
		Scholten Series Profile			Poynor Series Profile		
January	0.0	4.5	4.5	0.37	4.4	4.4	0.20
February	2.3	4.9	2.6	0.39	4.9	2.6	0.22
March	6.9	6.9	0.0	0.40	7.2	0.3	0.24
April	13.1	11.3	-1.8	0.40	11.9	-1.2	0.21
May	17.8	15.4	-2.4	0.40	16.5	-1.3	0.19
June	22.3	19.2	-3.1	0.37	20.6	-1.7	0.14
July	23.7	21.3	-2.4	0.32	22.5	-1.2	0.08
August	23.0	22.0	-1.0	0.30	22.8	-0.2	0.09
September	20.2	20.7	0.5	0.32	21.2	1.0	0.08
October	13.3	16.8	3.5	0.34	17.0	3.7	0.11
November	6.1	11.2	5.1	0.35	11.4	5.3	0.14
December	2.6	7.6	5.0	0.37	7.5	4.9	0.18
Mean	**12.6**	**13.5**	**0.9**	**0.36**	**14.0**	**1.4**	**0.16**

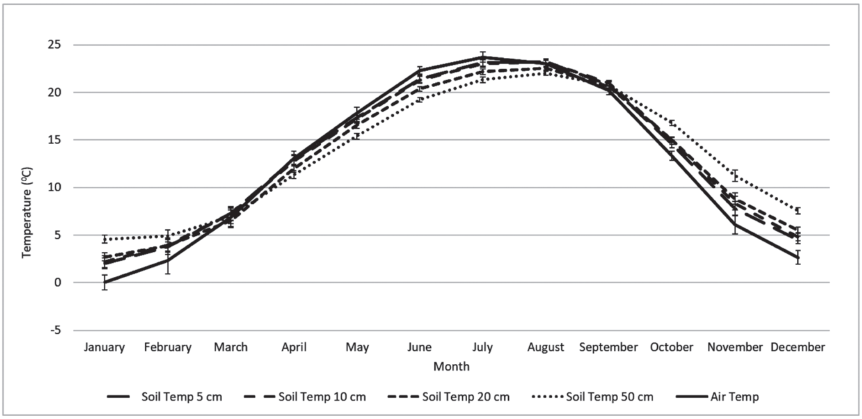

FIGURE 6. Mean monthly air and soil temperature data at different depths for Scholten soils (2012-2019). Error bars represent ±1 standard error.

C, respectively) than the Poynor pedon mean soil temperature (Figure 8) despite their close proximity. The temperature differences are explained by differences in the mean soil water content. The mean soil water content of the Scholten pedon during these months was (0.40 m^3/m^3 in May, 0.37 m^3/m^3 in June and 0.32 m^3/m^3 in July), more than two times the soil water content of the Poynor pedon. Greater soil water content occurs despite the Scholten's siltier texture and greater coarse fragment content at that depth which together would normally decrease the water holding capacity. This greater mean

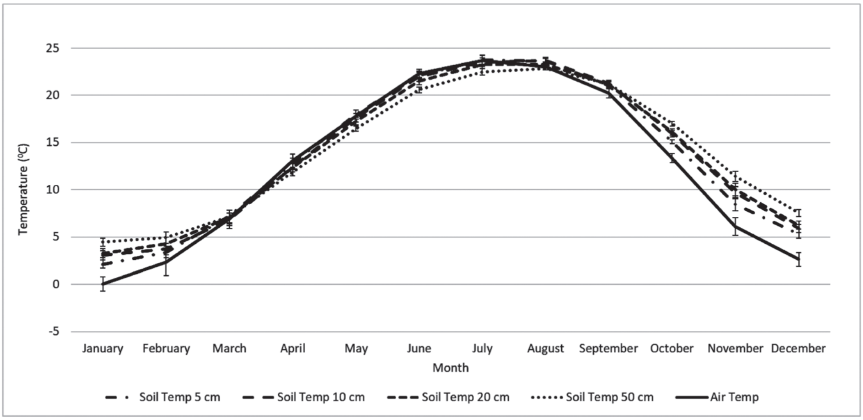

FIGURE 7. Mean monthly air and soil temperature data at different depths for Poynor soils (2012-2019). Error bars represent ±1 standard error.

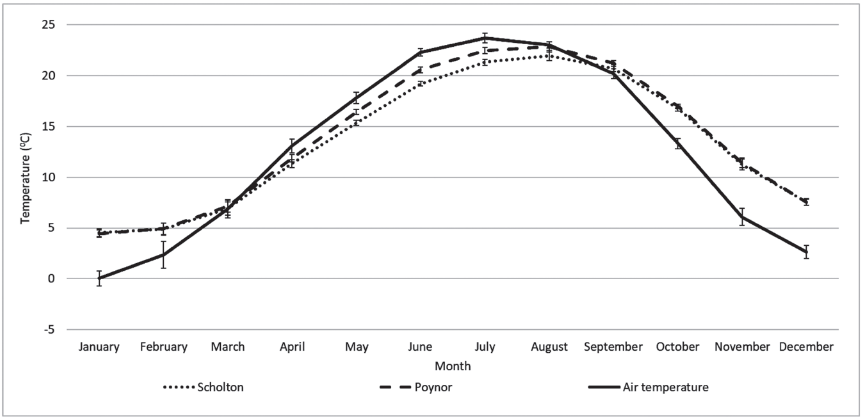

FIGURE 8. Mean monthly soil temperature (50 cm) and air temperature for the Scholten and Poynor pedons at the Journagan Ranch SCAN station. Error bars represent 1 standard error.

soil water content increases the heat capacity of the Scholten pedon causing the horizons to remain cooler than the Poynor pedon at the same depth during the summer months. According to our observations it is possible that the fragipan in the Scholten pedon acts as a barrier to downward water movement (Buol et al., 1997) that also restricts rooting and water uptake by plants. The combination of the restricted water movement and restricted rooting causes the Scholten pedon to have a greater soil water content that reduces warming during the late spring and early summer months. Smaller differences in soil temperature between the two pedons occurred during the autumnal cooling period and during the cold winter months when soil temperatures at 50 cm are moderated by the zone below the solum. Thus, even though the recorded mean summer soil temperature of the Poynor pedon (22.0° C) was 1.2° C warmer than the Scholten pedon's mean summer soil temperature (20.8° C), the opposite occurred during the winter. Then the Poynor soil's mean winter soil temperature recorded (5.6° C) was 0.1° C cooler than the Scholten's (5.7° C).

Taxonomic classification of sampled pedons

The taxonomic classification of the Scholten series is *loamy-skeletal, siliceous, active, mesic Typic Fragiudults*, and for the Poynor series is *loamy-skeletal over clayey, silicious, semiactive, mesic Typic Paleudults* (Soil Survey Staff, 2014). The Scholten pedon (Table 2; Figure 4) and the Poynor pedon (Table 3; Figure 5) are classified within their series range (Soil Survey Staff, 2021a; 2021c). Soil temperature measurements (Table 4) collected in this study support the mesic family class of both pedons (Soil Survey Staff, 2014).

Scholten and Poynor soil series are recognized and mapped together with other soils (complexes) in 31 Missouri counties primarily in the mesic region of the Ozark Highlands, Springfield Plain and the St. Francois Knobs and Basins MLRAs (116A, 116B and 116 C respectively) (Figure 2). Both soil pedons are classified as Ultisols at the order level but will vary in soil-landscape settings (e.g., Figure 1) and the presence of a fragipan and expression of fragic characteristics throughout the region of interest in this study. This will also influence air temperature/soil temperature relationships. The experimental design of this study could be used as a guide for further understanding of the influences of soil forming factors and soil forming processes on soil temperature at various geographic scales of interest.

Future soil temperature study considerations

This study compared adjacent Ultisols, a Typic Fragiudults and a Typic Paleudults. Even though the soil profiles were in close proximity, there were distinct differences in soil horizons and soil horizon expression. This emphasizes the importance of understanding soil forming factors and soil forming processes over short distances (e.g., soil landscapes or catenas) or longer distances (e.g., Major Land Resource Areas or Soil Temperature Regimes) when studying soil temperature variation both in space and time. The experimental design in this study provides a starting point for replicated future studies with these soils over either short or long distances. This approach also serves as an example for future soil temperature studies to maximize data collection in space and time, and to provide robust soil temperature data sets for more detailed statistical analysis and interpretation.

CONCLUSIONS

The soil temperature regime class identified in this study is the mesic regime. The mean annual soil temperature in the Ozark Highlands can be estimated by adding 1.1° C to the mean annual air temperature. According to the data, it is possible that the mean annual soil temperature of fragipan soils is cooler than similar soils with no fragipan properties. The fragipan acts as a physical barrier to water and air movement in the soil during the warmer months and reduces soil temperature. Similar studies should be conducted in other adjacent soils with the presence and absence of fragipans to validate this theory. The collection of additional data in future years will strengthen our observations of temperature variations in these soils and help guide us in the experimental design of future soil climate studies.

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