T.R.
ONDOKUZ MAYIS UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
DEPARTMENT OF SOIL SCIENCE AND PLANT NUTRITION

THE DYNAMIC OF SOIL MOISTURE AND TEMPERATURE IN THE SOILS OF THE PIENINY NATIONAL PARK

Master's Thesis

Razia Sultana SHAKY

Supervisor
Prof. Dr. Tomasz ZALESKI
II. Supervisor
Assoc. Prof. Dr. Coşkun GÜLSER

SAMSUN
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This thesis was supported by the European Union project of Erasmus Mundus Joint Master Degree in Soil Science (emiSS) with project number 610528-EPP-1-2019-1-TR-EPPKA1-JMD-MOB

SAMSUN
2023

ACCEPTANCE AND APPROVAL OF THE THESIS

The study entitled **"THE DYNAMIC OF SOIL MOISTURE AND TEMPERATURE IN THE SOILS OF THE PIENINY NATIONAL PARK "** prepared by **Razia Sultana SHAKY**, and supervised by **Prof. Dr. Tomasz ZALESKI and Assoc. Prof. Dr. Coşkun GÜLSER** was found successful and unanimously accepted by committee members as Master thesis, following the examination on the date 21.8.2023.

	Title Name SURNAME **University** **Department/Art**	**Final Decision**
Chairman	Prof. Dr. Coşkun GÜLSER Ondokuz Mayıs University Department of Soil Science & Plant Nutrition	☒ Accept ☐ Reject
Member	Assoc. Prof. Dr. Ammar ALBALASMEH Jordan University Science and Technology	☒ Accept ☐ Reject
Member	Prof. Dr. Orhan DENGİZ Ondokuz Mayıs University Department of Soil Science & Plant Nutrition	☒ Accept ☐ Reject

This thesis has been approved by the committee members that already stated above and determined by the Institute Executive Board.

.

Prof. Dr. Ahmet TABAK
Head of Institute of Graduate Studies

DECLARATION OF COMPLIANCE WITH SCIENTIFIC ETHIC

I hereby declare and undertake that I complied with scientific ethics and academic rules in all stages of my Master's Thesis, that I have referred to each quotation that I use directly or indirectly in the study and that the works I have used consist of those shown in the sources, that it was written in accordance with the institute writing guide and that the situations stated in the article 3, section 9 of the Regulation for TÜBİTAK Research and Publication Ethics Board were not violated.

Is Ethics Committee Necessary?

Yes ☐ (If it necessary, please add appendices.)

No ☒

10 /07/ 2023.
Razia Sultana SHAKY

DECLARATION OF THE THESIS STUDY ORIGINALITY REPORT

Thesis Title : THE DYNAMIC OF SOIL MOISTURE AND TEMPERATURE IN THE SOILS OF THE PIENINY NATIONAL PARK

As a result of the originality report taken by me from the plagiarism detection program on 10 /07/2023 for the thesis titled above;

Similarity ratio : % 24

Single resource rate : % 4 has been released.

10 /07 / 2023
Prof. Dr. Tomasz Zaleski
Assoc. Prof. Dr. Coşkun Gülser

ÖZET

PIENINY MİLLİ PARKI TOPRAKLARINDA TOPRAK NEMİ VE SICAKLIĞININ DİNAMİĞİ

Razia Sultana Shaky
Ondokuz Mayıs Üniversitesi
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Toprak Bilimi ve Bitki Besleme Ana Bilim Dalı
Yüksek Lisans, Haziran/2023
Danışman: Unvanı Prof. Dr. Tomasz ZALESKİ
II. Danışman: Prof. Dr. Coşkun GÜLSER

Arazi kullanımındaki değişiklikler, toprak nem seviyelerini ve sıcaklığını etkileyebilir ve bu da besin mevcudiyeti dahil olmak üzere çeşitli toprak özelliklerini etkiler. Bu çalışmanın amacı, i) Karpatlar'daki Pieniny Ulusal Parkı koruma alanındaki benzer pedo-iklim koşulları altında iki arazi kullanım sistemi (bir çayır ve üç ormanlık alan) arasındaki etkileşimleri ve toprak sıcaklığı ve nem dinamiklerini değerlendirmektir. Güney Polonya Dağ Sistemi ve ii) toprak sıcaklığı ve nem sensörlerinden toplanan verileri kullanarak toprak ve eğim yönü arasındaki ilişkiyi değerlendirmektir. Bu çalışma, Polonya'daki Pieniny Ulusal Parkı'ndaki çayır ve üç ormanlık alan gibi dört toprağı içermektedir. Bu toprakların fiziksel ve kimyasal karakterizasyonu, çayırların asidik topraklara sahip olduğunu, orman topraklarının ise asidik ila alkalin olduğunu göstermiştir. Ayrıca orman topraklarındaki toprak organik madde içeriği çayır toprağına göre daha yüksek bulunmuştur. Tüm topraklar arasında Şubat ayı en yüksek nem içeriği ve en düşük sıcaklığı sergilerken, Ağustos ayı en düşük nem içeriği ve en yüksek sıcaklığı göstermiştir. Ayrıca, toprak nemi ve sıcaklığında dikkate değer mevsimsel değişimler gözlenmiştir. Toprak sıcaklığı sonbahardan yaza keskin bir artış, ardından ilkbahar ve kış aylarında düşüş yaşadı. Tersine, nem içeriği ilkbahardan kışa önemli ölçüde artmış ve sonbahardan yaza doğru azalmıştır. Özellikle, orman topraklarında kuzeye bakan yamaçlarda toprak sıcaklığı daha yüksekken, güneye bakan yamaçlarda sürekli olarak daha yüksek toprak nemi vardır. Ek olarak, tüm topraklarda toprak nemi içeriği, toprak sıcaklığı ve toprak profilindeki derinlik arasında doğrusal bir ilişki vardır.

Anahtar Sözcükler: Toprak iklimi, Toprak nemi, Toprak sıcaklığı, Arazi kullanımı, Dağ toprağı, Orman toprakları.

ABSTRACT

THE DYNAMIC OF SOIL MOISTURE AND TEMPERATURE IN THE SOILS OF THE PIENINY NATIONAL PARK

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Master, August/2023
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Changes in land use can impact soil moisture levels and temperature, which in turn affect various soil properties including nutrient availability. The objective of this study is i) to evaluate the interactions between two land use systems - a meadow and three forested areas as well as the dynamics of soil temperature and moisture under similar pedo-climatic conditions in the Pieniny National Park conservation area in the Carpathian Mountain System of southern Poland and ii) to assess the relationship between soil and slope direction by using the data that have been collected from soil temperature and moisture sensors. This study included four soils in Pieniny National Park in Poland such as meadow and three forested areas. Physical and chemical characterization of these soil exhibited that meadow has acidic soil whereas forest soils are acidic to alkaline. In addition, soil organic matter content was higher in forest soils than the soil of meadow. Among all soils, February exhibited the highest moisture content and the lowest temperature, while August showed the lowest moisture content and the highest temperature. Moreover, notable seasonal variations were observed in soil moisture and temperature. Soil temperature experienced a sharp increase from autumn to summer, followed by a decline during spring and winter. Conversely, moisture content significantly increased from spring to winter and decreased from autumn to summer. Notably, the soil temperature was higher on north-facing slopes in the forest soils, while the south-facing slopes consistently had higher soil moisture. Additionally, across all soils, there was a linear correlation between soil moisture content, soil temperature, and depth in the soil profile.

Keywords: Soils climate, Soil moisture, Soil temperature, Land use, Mountain soil, Forest soils.

ACKNOWLEDGEMENT

I would like to express my gratitude to my supervisors Professor Dr. Tomasz Zaleski and Assoc. Professor Dr. Coşkun Gülser for guiding me in the completion of this thesis. I'm immensely grateful to Dr. hab. Agnieszka Rutkowska, prof. URK for her invaluable assistance in statistical analysis. And special gratitude to the Authority of Erasmus+: Erasmus Mundus Joint Master Degree for providing me the opportunity to study under this program.

I would like to express my appreciation to my mother for her unwavering support.

Razia Sultana SHAKY

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1. INTRODUCTION

Soil is the most valuable non-renewable resource on earth and arguably the most biologically diverse part of the biosphere (Barrett and Petropoulos, 2013). Drainage, the activity of microorganisms, the topography of the land surface, climatic factors, and both flora and fauna are the environmental factors that influence soil development (Norton and Smith, 1930).

Soil water potentially affects the hydrological, ecological, agricultural, and meteorological processes at the local, regional, and global levels. As a variable involved in the energy exchange between the land surface and the atmosphere, it has a significant role in soil quality estimations and projection strategies. Since the European Union's Soil Strategy for 2030 aims to integrate ecosystems and their services for decision-making, the measurement of its spatio-temporal variations and the development and use of digital and remote sensors to assess soil quality have drawn an enormous amount of attention and become an integral component of the soil conservation and restoration strategy (Anjos, L., et al. 2015; Kueppers et al. 2008; Mengistu et al., EC, 2022).

The continuous social, cultural, and economic adaptions of humans have had a negative impact on the provision of ecosystem services and a change in land use (Deng et al., 2016; Jiang et al., 2015; Kuppers et al., 2008) that directly affects climate change at local and regional scales (Betts et al., 2007) and simultaneously alter the physical (soil structure and bulk density) (Reyer et al., 2012), chemical (carbon storage), and biological (diversity of microorganisms) properties of soil (Feng & Liu, 2015; Hirsch et al., 2014; Sokotowska et al, 2020a, 2020b; H. Wang et al., 2010).

Besides, the slope aspect is regarded to be the most influential driver of environmental factors in the forest ecosystem in temperate regions (Singh, 2018). Soil temperature depends on the amount of solar energy which reaches the soil surface. The sunlight that the soil surface receives is directly proportional to the soil temperature (Onwuka, 2018). Soils in slope area receive a small amount of radiation compared to soils in the flat area because, in the slope area, the radiation is scattered over a wide range, so the soil temperature decrease as the slope land increase (Elizaberashivili et al., 2007). Moreover, in the northern hemisphere, south-facing slopes get higher direct radiation than the north-facing slopes. The slope area facing the equator receives more sunlight for long duration. South-facing slopes had greater soil temperatures and deeper active layers than north-facing slopes (Singh, 2018).

The monitoring and tracking of soil moisture and temperature on a long-term scale, which is essential for the sustainable management of water resources, the evaluation of large-scale model parameterization schemes, and the decision-making and integration of policies based on the protection of ecosystems, is particularly limited both in Europe and in the rest of the world mainly due to the high cost of covering extensive areas and to the fact that years of monitoring are required to generate reliable and useful information.

The objective of this study is i) to assess the interaction between two land use systems (a meadow and three forested areas) and the dynamics of the moisture and temperature of soils under similar pedo climatic conditions, located within the Pieniny National Park conservation area in the Carpathian Mountain System of southern Poland and ii) to evaluate the relationship between soil and slope direction by using the data that have been collected from soil temperature and moisture sensors.

2. LITERATURE REVIEW

2.1. Land use

Typically mountain soils contain shallow soils on steep slopes that have attracted very little consideration from the soil science community. The shallow soils, which are typical of many mountain soils, are only acknowledged at the (lithic) sub-group level of soil classification in Soil Taxonomy (United States, 1975), which groups all soils less than 50 cm thick with hard rock. In contrast, the FAO recognized three main types of mountain soils—lithosols, rendzinas, and Rankers—at the highest level of classification when the Legend of the Soil Map of the World was first published in 1974. Leptosols are thought to be the most widespread soil in the world, covering an estimated 1655 million hectares (ha) (ISSS Working Group RB 1998), 545 million of which are found in hilly regions. The most typical Leptosol-associated soils in hilly regions are Regosols and Cambisols, both of which are distinguished by their limited soil profile development (Nachtergaele, F., 2010). According to World Reference Base, Luvisol is characterized as the soil in which clay has been washed out of the upper layer of the soil and deposited in the lower layer of the soil, and contains moderate to high activity clays and low level of aluminum (Aide, M., 2004).

With the advent of agriculture, the use of the land changed from native woods to arable soils. The initial studies of anthropogenic landscape changes were carried out in Chile by Fuente and Hajek in 1979. Wilson et al. (2005) then looked into the reasons for the destruction and fragmentation of native forests in central and southern Chile. According to their findings (Donoso & Lara 1996), the primary causes of these modifications were: (i) adaptation to agriculture; and (ii) growth of forest plantations as a result of state policy. All these human-made operations took place on volcanic ash soils, comprising human-made operations took place on volcanic ash soils, which comprise less than 1% of the earth's overall but 60% of Chile's arable soils (Besoain and Seplveda, 1985).

Numerous soils, including Typic Hapludands (also known as Trumaos) in southern Chile, have had the impact of changing land use documented on their physical characteristics and pore functions (e.g., Indorante et al., 2013; Dörner et al., 2009, 2010, 2015). However, very few research has been done on Ñadi (Aquands) soils, (Ellies, 2001; Thiers et al., 2007; Dörner et al., 2016). These soils, which span an area of roughly 475.000 hectares and are found between 38º30`` – 43º00`` S, account for

9% of the country's andisols (Ciren, 2003). The shallow soil depth of Ñadi soils, which can be between 20 cm and 90 cm, is associated with their fragility (Ciren, 2003). The latter component is significant because the depth of the soil, which is directly influenced by changes in land use and cover, also has an impact on other soil characteristics and processes, for instance, water holding capacity, soil temperature, and water dynamics.

2.2. Soil water

Soil water content is one of the crucial factors that determine soil ecosystem health. It plays a crucial role in the growth and development of plants and also in the survival of soil-dwelling organisms. The water-retaining capacity of soil largely depends on the texture and organic matter content of soil; soil can hold more water if it contains a higher amount of smaller particles like clay or organic matter (Ankenbauer et al., 2015). There is a corresponding relation between soil organic matter (SOM) content and water holding capacity of soil; which makes the SOM one of the significant determinants of soil water-holding capacity (Hudson, 1994). For better understanding of this interaction between the physical and chemical processes of soil and soil water contents (SWC), field measurements can be carried out. There are two vital threshold values for plant-available water e.g., field capacity (FC) and wilting point (WP) because above FC waterlogging can occurred where below wilting point plants will wither as they will unable to absorb moisture (Kirkham, 2014). Therefore, in order to maintain a sustainable ecosystem, it is vital to analyze changes in the amount of water that plants will have access to as a result of climate change.

In general, the amount and composiotion of water greatly influences the physical, chemical, and biological activities that occur in soil. Water must flow across the soil surface, reach the soil profile, or finally percolate to recharge aquifers in the case of the water infiltration process, which is necessary to comprehend the hydrological cycle (Cerdà, 1999). Irrational land use is known to have an impact on soil water, which can lead to poor germination and decreased yields (Abadi Ghadim, 2000), accelerated agrochemical leaching (Taumer et al., 2006), increased runoff and enhanced erosion (Hao, X., et al., 2020). In an agricultural catchment of the Loess Plateau, Li et al. (2009) demonstrated that a change in land use from wood to grassland decreased soil water by 18% between 1981 and 2000. According to Cerdà (2000), soil erodibility was higher under agricultural land usage than it was in scrubland in arid areas, suggesting that farming the land under some circumstances may help to increase soil erosion and runoff. Soil water variations under various land use types must be understood in order to effectively manage agricultural water resources and control land erosion (Gao et al., 2014; Starr, 2005; Ziadat and Taimeh, 2013).

2.3. Soil temperature

The primary determinants of soil temperature are solar radiation and air temperature, but there are many additional variables that also play a role, including precipitation, soil texture, moisture content, and the type of surface cover (snow, crop residue, plant canopy, etc.) (K. I. Paul et al. 2004). Although daily, weekly, and yearly averages of soil temperature readings are routinely published, soil variability is similarly significant (B. Bond-Lamberty et al., 2005). Despite this, many meteorological stations only monitor aboveground variables (such as air temperature), or the soil temperature sensors are placed at the station rather than at the experimental site's plots (close to the mast that supports other sensors and the data logger), which may lead to the measurement of unrepresentative amounts of data.

2.4. Impacts, interactions, and modeling strategies for spatial-temporal dynamics of soil water content and temperature

Fluctuations in soil water content occur at various spatial and temporal scales. At the vertical spatial level, near-surface hydrological processes exhibit rapid responses to climatic changes, resulting in significant fluctuations and instability in water movement. The influence of precipitation becomes noticeable in the upper 0-10 cm soil depth even after the first rainfall event. However, changes in water content at depths of 10-20 cm are not sufficient and require at least two or more precipitation events to modify the moisture levels [Du et al., 2021; Holsten et al., 2009; Lal Rattan & Shukla Manoj K, 2004; Petropoulos & McCalmont, 2017; Y. Wang et al., 2021; Z. Guang Xu et al., 2021; Yang et al., 2021]. Moisture and temperature play crucial roles in influencing various soil processes and have a significant impact on ecosystem functions. Temperature governs soil-atmosphere heat transfer, soil-plant-atmosphere gas exchange, climate regulation, chemical and biophysical reactions in the soil, as well as plant growth and development, particularly during germination [Aalto et al., 2018; Audia et al., 2021; Gonzalez-Rouco et al., 2003; Hincapie Gomez et al., 2012; Houle et al., 2012; Kueppers et al., 2008; Mengistu et al., 2021; Palm et al., 2007; Qian et al., 2011; Sun et al., 2012; Y. Zhang et al., 2005]. On the other hand, water in the soil directly influences the buffering and regulation of the hydrogeological cycle, aquifer recharge, control of runoff, water availability for plants, distribution of nutrients and pollutants, and soil formation [Aalto et al., 2018; Audia et al., 2021; Hincapie Gomez et al., 2012; Houle et al., 2012; Mengistu et al., 2021; Qian et al., 2011; Sun et al., 2012]. Efforts to quantify and monitor these complex soil dynamics have been increasing, as understanding their spatio-temporal variations contributes to more accurate scaling of hydrological models. Various modeling approaches exist, including those focusing on regional and global scales, such as multi-layer submodels that estimate values on vegetated surfaces using climate variables, and remote sensing models that predict droughts and forest fires using satellite imagery. These models offer wide coverage and easy accessibility; however, most of them primarily consider the impact of a single climatic factor or surface layers less than 10 cm deep, and no single factor can fully explain soil variation [Feng & Liu, 2015; Holsten et al., 2009]. On the contrary, there are models that concentrate on local scales, incorporating vertical spatial variations. For instance, retention curve models (SWRC) estimate water flux and availability in the soil using pedotransfer functions based on particle size, soil organic carbon, bulk density, and equations of fluid flow in porous media [Hillel, 1998]. The accuracy and modeling of these models depend on defining the primary hydraulic functions of conductivity and moisture retention in advance, thus requiring a comprehensive understanding of soil-water processes and in-situ measurements. Various combinations of sensors can be employed to estimate variations in soil water content at different matrix potentials (Feng & Liu, 2015; Baveye, et al., 2016; Z. Guang Xu et al., 2021).

Modeling soil temperature is essential for comprehending soil processes in addition to soil water content. According to Y. Luo et al. (1992), there are three categories of soil temperature models: (1) Mechanistic models that concentrate on physical processes (radiative energy balance as well as sensible, latent, and ground-conductive heat fluxes) to predict the upper boundary temperature and estimate the temperature of deeper layers with Fourier's equation(C. H. M. van Bavel et al.,1976); (2) mixed empirical and mechanistic models; and (3) empirical models that are based on statistical relationships between soil temperature at some depth and climatological and soil variables (T. J. Toy et al., 1978) (P. J. Wierenga et al.,1970).

2.5. Influence of slope direction on soil temperature and moisture levels

Solar radiation is the primary source of soil temperature (Onwuka and Mang, 2018), and temperature variation significantly impacts both biological and chemical activities in the soil. Daily and annual fluctuations in soil temperature influence decomposition rates, mineralization of organic matter, CO2 emissions (Paul et al., 2004), seed germination, root development, absorption rates, and soil evaporation rates. Differences in slope aspect also contribute to temperature variations, affecting the development of soil characteristics. Almost every soil function, from primary mineral weathering to plant nutrition and organic carbon storage, is influenced by soil temperature (Pregitzer and King, 2005). Meteorological conditions like solar radiation and air temperature, site topography including slope aspect and gradient, soil moisture content and texture, and the extent of surface covered by litter and plant canopies all influence soil temperature (Paul et al., 2004). South-facing slopes generally exhibit higher soil temperatures and deeper active layers compared to north-facing slopes (Singh, 2018). A study by Geroy et al. (2011) investigated the effect of different slope aspects on soil water in northern Boise, Idaho, USA. Monitoring soil temperature and moisture on south- and north-aspect slopes during the spring and summer of 2009, they found that the south-facing slope had higher soil temperature due to increased solar radiation. Furthermore, north-facing slopes had higher volumetric soil moisture content compared to south-facing slopes, indicating their ability to retain more water (Geroy et al., 2011).

3. MATERIAL AND METHODS

3.1. Study Area

This research was conducted in Pieniny National Park (PNP) in the Carpathian Mountains in southern Poland. The Pieniny range, located in the western Carpathian Mountains, runs along a parallel of latitude, and is 10 km long and 4 km wide. The mountains are relatively low, with an elevation change of 557 m (the highest peak – Mt Trzy Korony – 982 m above sea level). Geographically it is an exceptionally varied mosaic with steep, open, jagged peaks, rock walls and shelves, as well as gentle hill tops and crests covered with forests and fields. The sculpture of the Pieniny Mts is unusually asymmetrical. The northern slopes, crossed by a thick network of valleys, gently fall into the Krośnica Stream Valley. From the main ridge on the southern side, buttresses extend which end in steep peaks, usually with perpendicular walls, falling straight into the Dunajec River Valley (Niemirowski 1982). The Pieniny National Park (PPN) covers 2346 ha and includes most of the Pieniny Mountains (Figure 1.). Protected since 1932, it is one of the oldest national parks in Poland, and one of the smallest of its kind in the country (Ciach, M. et al. 2005). The average annual temperature ranges between −6.7°C (in January) and 17.0°C (in July). Total annual precipitation ranges from 690 mm to 850 mm. Forests occupy 70% of PNP area and characterise high diversity of plant communities, which is caused by natural variability of the soil cover (Sokołowska J, Józefowska A, et al. 2019). Soils of PNP were classified to ten soil types however, these soils characterise similar features such as soil texture – silty or loamy and content of coarse fragments – medium or heavy (Zaleski et al. 2016). Most of the Pieniny forests belong to the Querco-Fagetea class and are found in the lower montane zone . The forest layer and the entire flora of this region are rich and extremely varied (Zarzycki 1982).

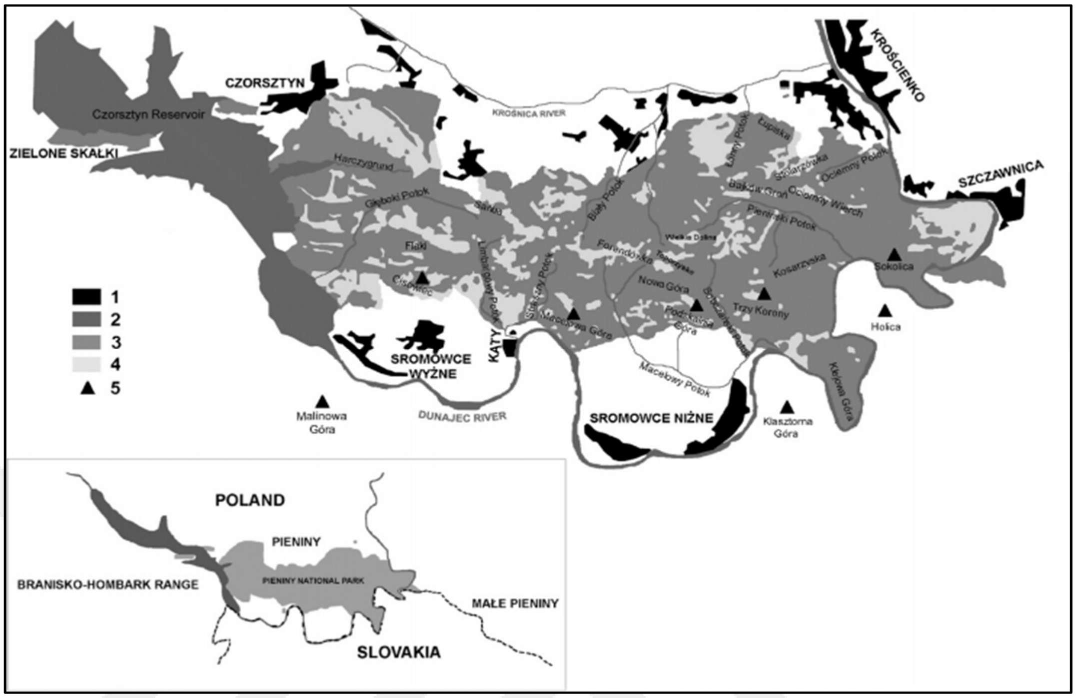

Figure 3. 1. Location and topography of the Pieniny National Park.1 – buildings; 2 – water reservoir and rivers; 3 – forests; 4 – meadows; 5 – peaks (source: Ciach, et al., 2005).

On the northern slopes, Carpathian beech forests Dentario glandulosae-Fagetum dominate, although there are significant amounts of mountain sycamore maple forests PhillitidoAceretum. On the southern slopes, there are primarily thermophilous fir-beech forests CariciFagetum (Pancer-Kotejowa 1973).

Forests cover approximately 71% of the PPN with a domination of fir Abies alba, beech Fagus sylvatica and spruce Picea abies. They create treestands of both single species as well as mixed species. The remaining part of the PPN is mainly covered with small, scattered fields and pastures. There is a clear difference between the eastern part of the PPN with its rich variety of species and treestands of extremely different ages and structures, and the western part where spruce treestands have been planted and there is little variety.

The Pieniny National Park also encloses a mosaic of open landscapes in which fields and pastures dominate, together with villages and the Dunajec River Valley. The Pieniny Mountains are characterized by a definitely milder climate than the surrounding Beskidy Mountain ranges. They have a higher mean annual temperature, less annual rainfall, shorter snow cover, and more days of sunshine. There is also a difference between the cooler, more humid climate of the northern slopes and the warmer, drier southern slopes (Kostrakiewicz 1982) (Ciach, M. et al. 2005). Soils with the same edaphoclimatic conditions and different land uses, located near the Czorsztyn region, were selected for the study.

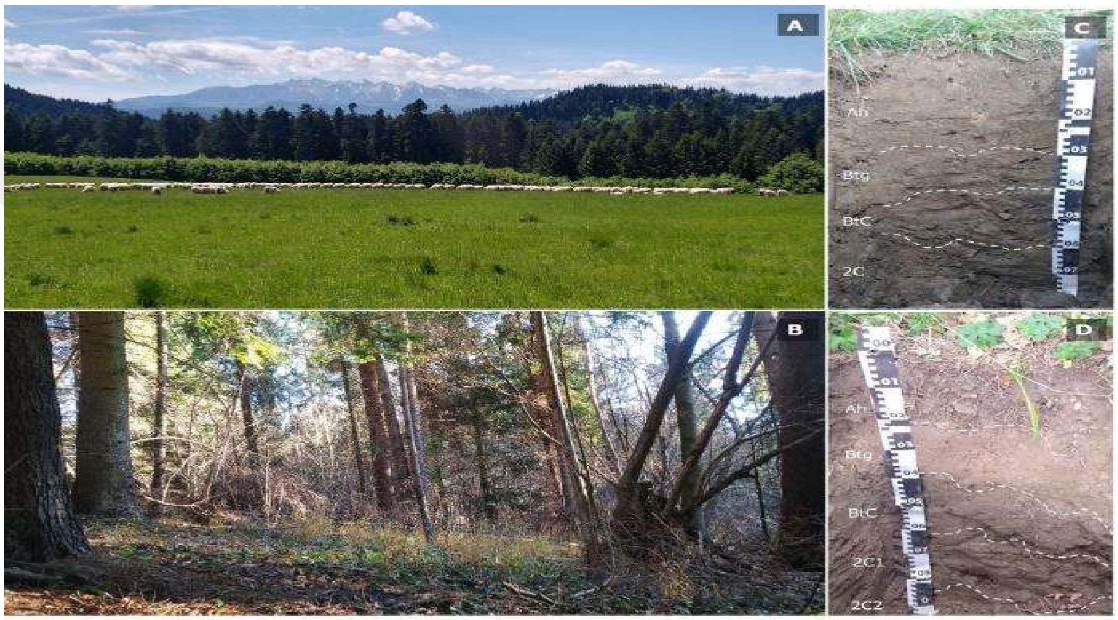

Figure 3. 2. Study site landscape, sampling locations, and soil profiles for the Meadow (up), and Forest_2 (below) (photo by Camila).

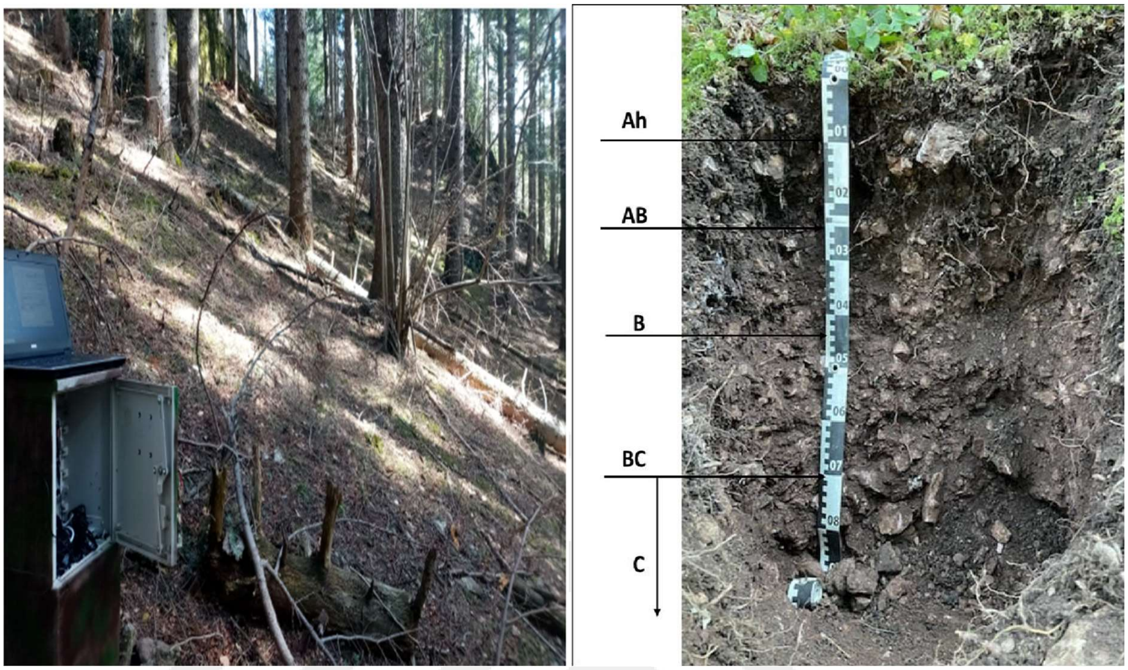

Figure 3. 3. Study site landscape, sampling locations, and soil profiles for the south facing Forest-3 (left) horizons (right) (photo by Razia and Nazier).

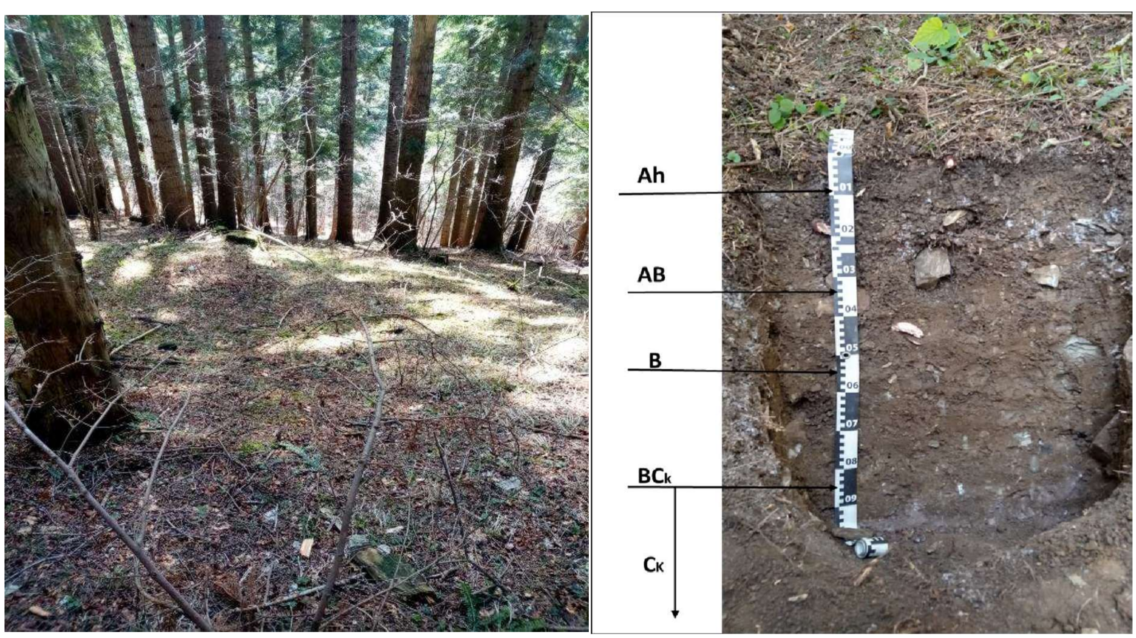

Figure 3. 4. Study site landscape, sampling locations, and soil profiles for the north facing Forest_4 (left) horizons (right) (photo by Razia and Nazier).

3.2. Soil Physical And Chemical Characterization

For the physical and chemical characterization of the soil, samples of the morphogenetic horizons of each profile were air-dried and then passed through a 2 mm-sized sieve, each analysis was conducted with two replications. Particle size distribution of sand (2.00-0.05 mm), silt (0.05-0.002 mm), and clay (0.002 mm) was determined using the hydrometer the Cassagrande method in modification of Prószynski (PN-R-04032:1998), contents are expressed as a percentage by mass of the fine earth fraction. Soil Organic Carbon (SOC) was estimated by wet digestion Tiurin's method modified by Oleksynowa (Oleksynowa et al., 1993); pH was measured potentiometrically in distilled H2O and KCl suspension using a solution ratio of 1:2.5.

3.3. Spatio-Temporal Dynamics of Soil Moisture Content and Temperature

The spatio temporal dynamics of soil moisture and temperature at the field scale were monitored during the period from March 2022 to April 2023. TEROS 11 Sensors (Meter Group, Inc) was used to estimate volumetric soil water content (θ m3·m-3), and temperature (°C) at the soil depths of 10, 20, 40, 60, and 80 cm.

For sensor installation, soil pits were dug at approximately 90 cm depth, the sensors were carefully hand located in a horizontal position into the pit sidewall such that the sensing components of the sensor resided in undisturbed soil volume, the pit was carefully backfilled to preserve the bulk density of the soil (Fig. 6). Soil moisture content and temperature status were recorded at 15 minutes intervals in the DECAGON Em50 data logger (Meter Group, Inc) which were located approximately 30 cm horizontally from the sensors in plastic containers within the soil.

The data sets were retrieved manually during routine field trips using ECH2O Utility software (ECH2O EC-5, Decagon Devices, Pullman, WA).

Figure 3. 5. TEROS 11 soil sensor locations at 10, 20, 40, 60, and 80 cm depths Em50 data logger installation on the study area (A, B- sensors, C, D- datalogger installation, E- underground data logger container system, F- aboveground data logger box (photo by T.Zaleski)

4. RESULTS AND DISCUSSION

The result of the chemical analysis of soil samples is shown in the following tables and graphs respectively. Microsoft Excel and analysis software R have been used for computing the data and preparing the tables and graphs. The obtained results are discussed as follows:

The detailed morphological description of the field profiles was performed following the FAO Guidelines and the soil reference groups were identified using the WRB classification (IUSS Working Group, 2015). The main characteristics of the sites studied are presented in Table 4.1:

Table 4. 2. Characteristics of the study sites

Soil profile	Mesoregion	Parent Material	Soil type WRB (2015)	Land Use
PPN1	Pieniny Klippen Belt	Limestone / loess-like sediments	Stagnic Endoskeletic Endocalcaric LUVISOL (Siltic, Cutanic, Raptic)	Meadow
PPN2	Pieniny Klippen Belt	Limestone / loess-like sediments	Stagnic Endoskeletic Endocalcaric LUVISOL (Siltic, Cutanic, Raptic)	Forest
PPN3	Pieniny Klippen Belt	Calcareous	Rendzic Leptosol	Forest
PPN4	Pieniny Klippen Belt	Calcareous	Rendzic Leptosol	Forest

4.1. Soil Physical and Chemical Characterization

4.1.1. Soil Texture

According to Table 2, the soils of the study region were characterized by medium to fine texture with a dominant silty loam and silty clay granulometry, evidencing the prevalence of silt within the soil profile for all of the land use systems. The meadow soils had noticeable variations in the granulometric composition between the organic-rich (Ah) and illuvial (Btg) horizons compared to the deluvial (BgC) and bedrock (2C) horizons.

Conversely, for the forest soils, this difference was only present for the bedrock horizon, which had the highest clay content in the profile. Among the forest soils, north facing forest soil had higher amount of clay content than the soil of south facing forest which is corresponding to a previous study, where it was found that the North-facing slope had higher clay content and lower sand than south-facing slope (Wang, L et al., 2008).

4.1.2. Soil pH

In all samples, the soil pH was greater at lower horizon than at the surface. Hence, the soil pH increases with the depths in the soil profile**.** pH of east and west-facing meadow (5.05-6.42)and forest_2 (3.64-6.73) was acidic in nature whereas that of south and north-facing forest 3 was alkaline (6.67-7.20) and forest 4 was acidic to alkaline in nature (5.79-6.98) **(**Table 2**).** The results also showed that, in the meadow, the surface horizons are strongly acidic while the horizons below 40 cm depth are slightly acidic. A similar trend can be observed in the forest soils, where the variation ranges from acidic to alkaline soils. Huang et al. (2015) found an increase in Soil pH as the depth increased from 10-30 cm to 30-60 cm and this finding is align with our results across the four land systems. That phenomena is common in soil of the Pieniny National Park (Niemyska-Łukaszuk at all 2004, Zaleski at al. 2016).

4.1.3. Soil Organic Matter Content

According to the following table 2, forest systems evidenced higher organic matter content in soil than the meadow land use system which was 6.94, 9.44, 14.12 and 9.99 for meadow, forest_2, forest_3, and forest_4 respectively, and among three forest system, the highest SOM found in the soil of south-facing (PPN3). The reason that might there is more Organic matter in south aspect than North is that; the higher the microbial utilization of soil organic matter for growth, the higher the death rate and turnover of the soil microbial biomass, and the faster the native soil organic matter is mineralized (Zhao and Li, 2017). The results also showed that organic matter was higher on the surface horizon than the below horizons and it showed a decreased manner with depths. Microbial activity and organic matter content, are both considered early and sensitive indicators of environmental change (Sidari et al. 2008). Soil temperature fluctuations affect both biological and chemical processes in the soil, such as rates of decomposition and mineralization of soil organic matter, as well as CO2 release (Paul, 2004).

Table 4. 3. Physiochemical soil properties on (a) Meadow, (b) Forest_2, (c) Forest_3, (d) Forest_4

Horizon	Depth (cm)	Textural class	Amount of sand, silt, and clay (%)			pH KCl	SOC g/kg	SOM %
PPN1: Meadow								
			sand	silt	clay			
A_h	0-30	Silty loam	7	79	14	5.05	5.80 ±0.13	9.98 ±0.23

B_{tg}	30-40	Silty clay loam	18	52	30	5.65	2.27 ±0.067	3.90 ±0.12
BtC	40-60	Silty clay	11	47	42	6.64	ND	ND
C	60-80	Silty clay	10	50	40	6.42	ND	ND
PPN2: Forest_2								
A_h	0-20	Silty loam	19	68	13	3.64	5.90 ± 0.04	10.15 ± 0.07
Btg	20-40	Silty loam	25	52	23	4.01	5.07 ± 0.08	8.72 ± 0.14
BtC	40-60	Clay loam	24	48	28	4.71	ND	ND
2C1	60-85	Clay loam	25	47	28	6.16	ND	ND
2C2	85-100	Silty clay	11	46	43	6.73		
PPN3: Forest_3								
A_h	10	Silty	5.3	84.7	10	6.67	14.82±0.17	25.55±0.30
AB	25	Silty	9.4	83.6	7	6.88	9.01±0.17	5.53±0.30
B	45	Silty loam	20.2	61.8	18	7.09	6.53±0.03	11.27±0.05
BCk	70	Silty loam	32.1	51.9	16	7.20	ND	ND
Ck	90	Silty	5.2	83.8	11	7.13	ND	ND
PPN4: Forest_4								
A	10	Silty loam	3.4	83.6	13	5.79	10.51±0.14	18.12±0.25
AB	35	Silty loam	23.4	56.6	20	6.63	6.36±0.26	10.97±0.45
B	55	Silty clay loam	3.5	63.5	33	6.37	6.31±0.09	0.87±0.15
BCk	85	Silty clay	5.4	50.6	44	6.79	ND	ND
Ck	>85	Silty clay loam	14.6	53.4	32	6.98	ND	ND

Sand fraction (2,00-0,05 mm); Silt fraction (0,05-0,002 mm); Clay fraction (<0,002 mm)
ND.: No Data available

4.2. Spatial and Temporal Variation of Soil Moisture in Different Land Use

The study concentrated on a meadow and three forest regions (Forest 2, Forest 3, and Forest 4) to better understand the temporal fluctuations in moisture content within diverse land use systems. In order to comprehend the entire dynamics of moisture, daily measurements of moisture content were recorded, and monthly trends were evaluated. The study additionally addressed moisture content variations and how it related to soil depth.

The highest daily moisture content recorded in the meadow was 0.46 m3·m-3 (VWC) on the 22nd of February, while the lowest value was observed on the 5th of July (0.12 m3·m-3). The moisture content of Forest 2 was at its peak on February 21 (0.46 m3·m-3) and at its lowest on August 12 (0.22 m3·m-3). The 18th of February (0.42 m3·m-3) noted the highest moisture content in Forest 3, and the 7th of September (0.28 m3·m-3) recorded the lowest. The maximum moisture content for Forest 4 was obtained on February 22 (0.32 m3·m-3), and the lowest value was recorded on August 12 (0.17 m3·m-3).

According to an analysis of monthly patterns, February consistently had the highest moisture content in all land use systems (meadow, Forest 2, Forest 3, and

Forest 4). For each of these measurements, moisture content was 0.43 m3·m-3, 0.39 m3·m-3, 0.45 m3·m-3, and 0.32 m3·m-3 in February (Fig. 6, 7, 8, 9). On the other hand, the lowest moisture content values were recorded in May for the meadow and in August for the forest systems. For the meadow, Forest 2, Forest 3, and Forest 4, the moisture content values were 0.25 m3·m-3, 0.35 m3·m-3, 0.40 m3·m-3, and 0.23 m3·m-3, respectively. Among the three forest soils, south-facing forest soil had higher moisture content than the north facing and east facing forest soils.

When the variations in moisture content were compared, it was found that the meadow had a higher variation (0.018 m3·m-3), whereas the forests had lesser variations (0.04 m3·m-3, 0.05 m3·m-3, and 0.09 m3·m-3 for Forests 2, 3, and 4, respectively).

In terms of depth, it can be demonstrated that throughout all land use systems, the average soil moisture content increased with depth. Particularly, the mean values for meadow, forest_2, forest_3, and forest_4 at depths of 10 cm, 20 cm, 40 cm, 60 cm, and 80 cm were 0.32 m3·m-3, 0.35 m3·m-3, 0.36 m3·m-3, 0.38 m3·m-3, 0.46 m3·m-3, and 0.24 m3·m-3, respectively. These findings indicate that forest_3 has a higher water-holding capability compared to the other land-use systems.

One of the important features of the study oil was its high amount of silt concentration. Previous studies have shown that adding a small proportion of Aeolian silt can significantly influence soil properties and formation (Audia et al., 2021). Besides granulometry, according to previous research pH values between 5.20 and 5.32, which are similar to those obtained in our studies, pointing that the physical, chemical, and hydraulic properties of the evaluated soils are parallel to those of the geographically surrounding areas of Carpathians (Niemyska-Lukaszuk, et al., 2004).

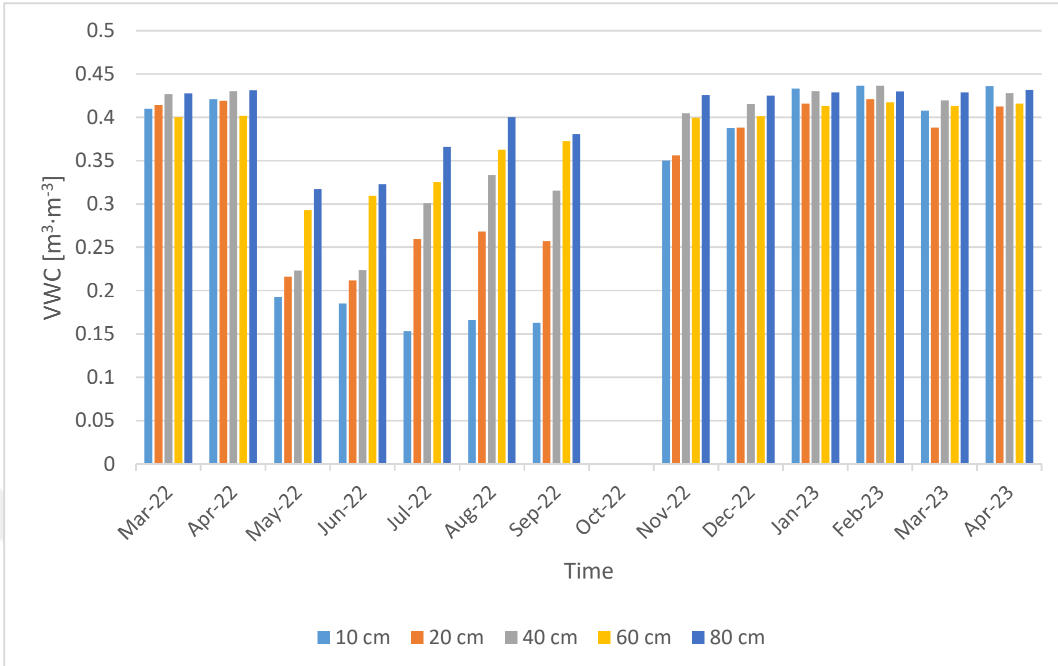

Figure 4. 1. Monthly means of moisture content in the soil of meadow

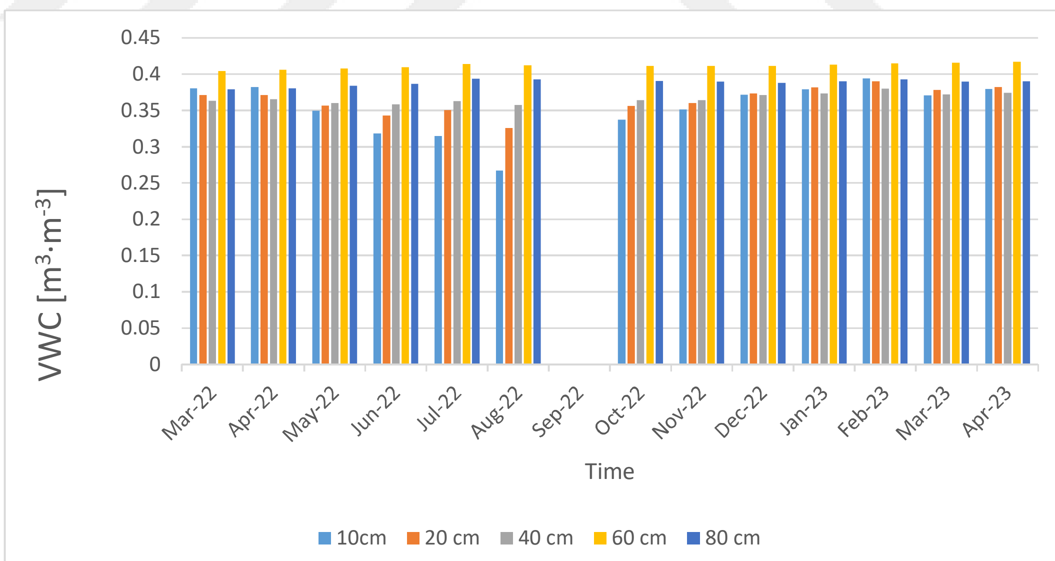

Figure 4. 2. Monthly means of moisture content in the soil of forest_2

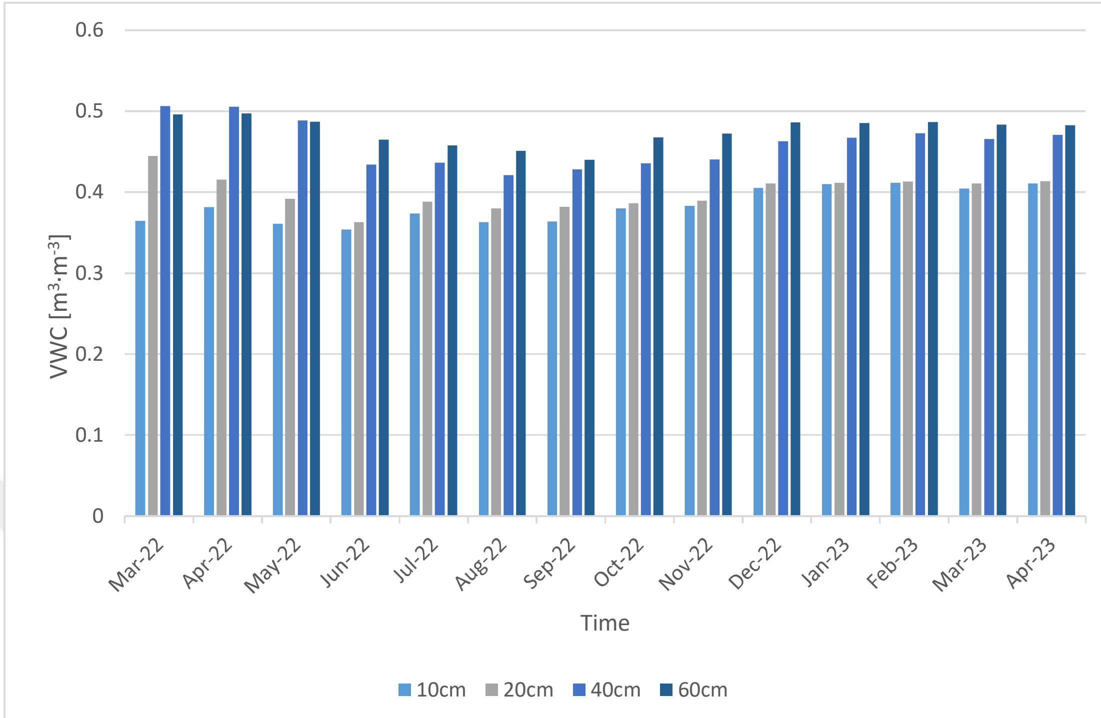

Figure 4. 3. Monthly means of moisture content in the soil of forest_3

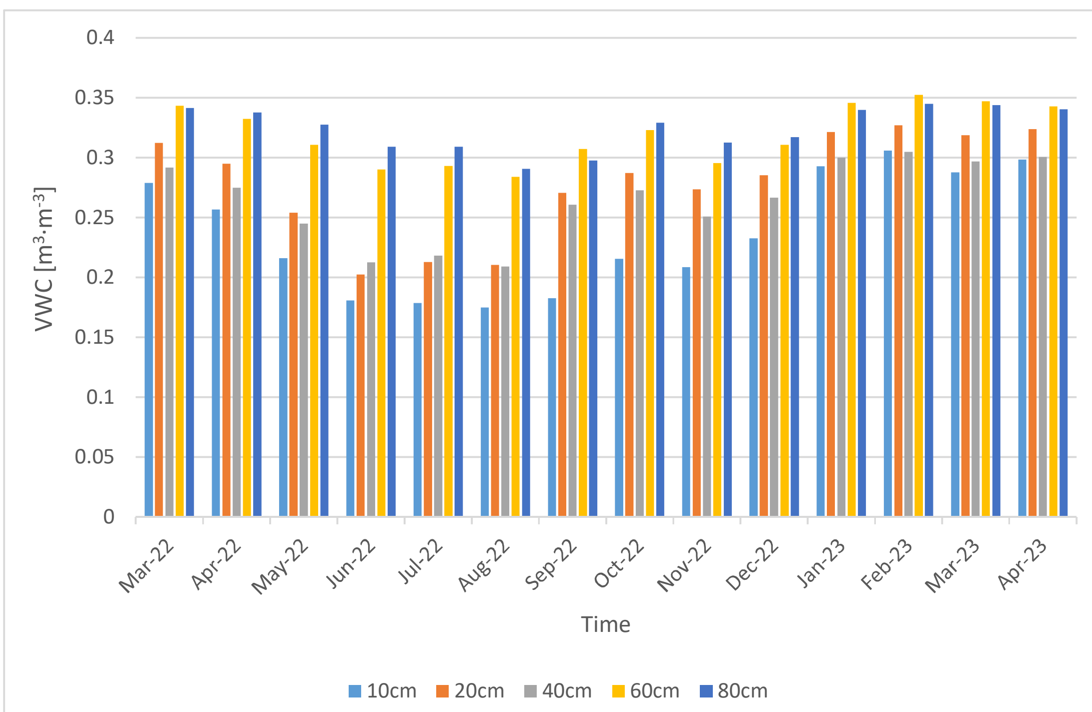

Figure 4. 4. Monthly means of moisture content in the soil of north-facing forest_4

Taking into account the spatial variation of soil moisture content and temperature, Wang et al., (2021) analyzed the fluctuation of soil moisture in the grassland which illustrated that microorganisms and plants are active in the horizons near to the surface, particularly between 0-20cm, also more prone to evapotranspiration, which is similar to the results obtained from our study soils (meadow and forest soils). Evapotranspiration acts as an upward force in the movement of water throughout the soil profile which makes it responsible for the availability of water in the soil surface (Lal et al., 2004). However, at the depth between 20-40 cm water movement is slower than that in the 0-10 cm layer (Wang et al., 2021). At this depth there are still changes in soil moisture after first precipitation take place (Du et al., 2021; Holsten et al., 2009; Lal Rattan & Shukla Manoj K, 2004; Petropoulos & McCalmont, 2017; Y. Wang et al., 2021; Xu, Z.G et al., 2021; Yang et al., 2021).

Previous research found results that are unlike our findings where it is explained that lower moisture occurs in deeper horizons (40-60 cm) because after precipitation it takes time to increase the water level at this depth. Several researchers showed that in arid regions at the same depth, these conditions can result in a dry soil layer which limits percolation. On the contrary, fluctuations in soil moisture are lower in the deeper horizons, particularly 60-100 cm (Buckman & Brady 1968; Du et al., 2021; Lal Rattan & Shukla Manoj K, 2004; Sun et al., 2012; Sun et al., 2019; Y. Wang et al., 2021; G. Xu et al., 2021; Yang et al., 2022).

Zaleski et al. found similar results in Retisols with loess deposits in Southern Poland which illustrated that this soil is characterized by two zones: an upper zone with humic and illuvial horizons and a lower zone comprising illuvial and parent material horizons; the boundary between these two zones was about 50 cm of depth, the upper zone had lower moisture content and relatively wider fluctuations in moisture than the lower zone (Zaleski et al., 2003, 2005, 2009, 2012).

A study reported that water storage in both upper (0-50 cm) and lower (50-100 cm) zones was higher in grassland than that in forest soils; moreover, higher vegetation leads to reduce moisture content in both surface and deeper layer in the soil profile (Feng & Liu, 2015; Baveye et al., 2016; Xu, Z.G., et al., 2021). This phenomenon can be understood by the following impact that vegetation cover and climate have influence on water retention in soil, i.e., the higher the plant density, the higher the precipitation uptake and the higher the Et rate, leaving the soil with less water; in addition, it was found that moisture content in soil reduced by 35% where vegetation restoration carried out (Zaleski et al., 2003, 2009, 2012).

4.3. Spatial and temporal variation of soil temperature in different land use

On a daily basis, the highest temperature was recorded on the 4th of July and the lowest was on the 20th of February for the meadow which was 22.01 and 0.38 °C respectively. In Forest 2, the highest was on the 19th of August (17.84) while the lowest was from the 4th of March to the 8th of March which was 0.40 °C. Similarly, the highest temperature recorded in the soil of Forest 3 was on the 20thAugustgust (17.28) and the lowest was from the 2nd of March to the 9th of March (0.90) and the highest was on the 20th of August (17.64) and the lowest was on 7th of March (0.86) the soil of Forest 4.

In addition, according to Figure 4.5, 4.6, 4.7, and 4.8, on a monthly basis, the highest temperature noted in the month of August for the meadow and for the three different forests (forest_2, forest_3, forest_4) which was 18.95, 16.09, 15.31, 15.77 °C respectively; and the lowest values were in the month of March 2022 and February 2023 for the meadow (1.38 and 1.62 °C respectively) and for the forest 2, it was on February (0.92); for the forest 3 it was in march 2022 and February 2023 which was 1.07 and 1.61 respectively; and the lowest temperature occurred in forest 4 in the month of march 2022 and February 2023 (0.94 and 1.34 respectively). However, in the meadow land use system, the monthly average temperature in March and April of 2023 was higher than that in 2022 of the same months. In a brief, soil temperature was highest in the soil of meadow than the forest soils; and in the consideration of forest soils, temperature was higher in the soil of north facing forest which is also evidenced by previous research where higher soil temperature found on the north than south-facing slope in a Pinus laricio forest ecosystem of Aspromonte, southern Italy; accordingly, the highest soil water content was on the south-facing slope (Sidari et al., 2008). Whereas unlike our study, Macyk et al., (1978) found that the Soil temperature was greater on the south-facing slope than on the north-facing slope, and air temperature was generally higher than soil temperature at the 10-cm depth, which is due in part to increased soil moisture levels on the slope's northern side.

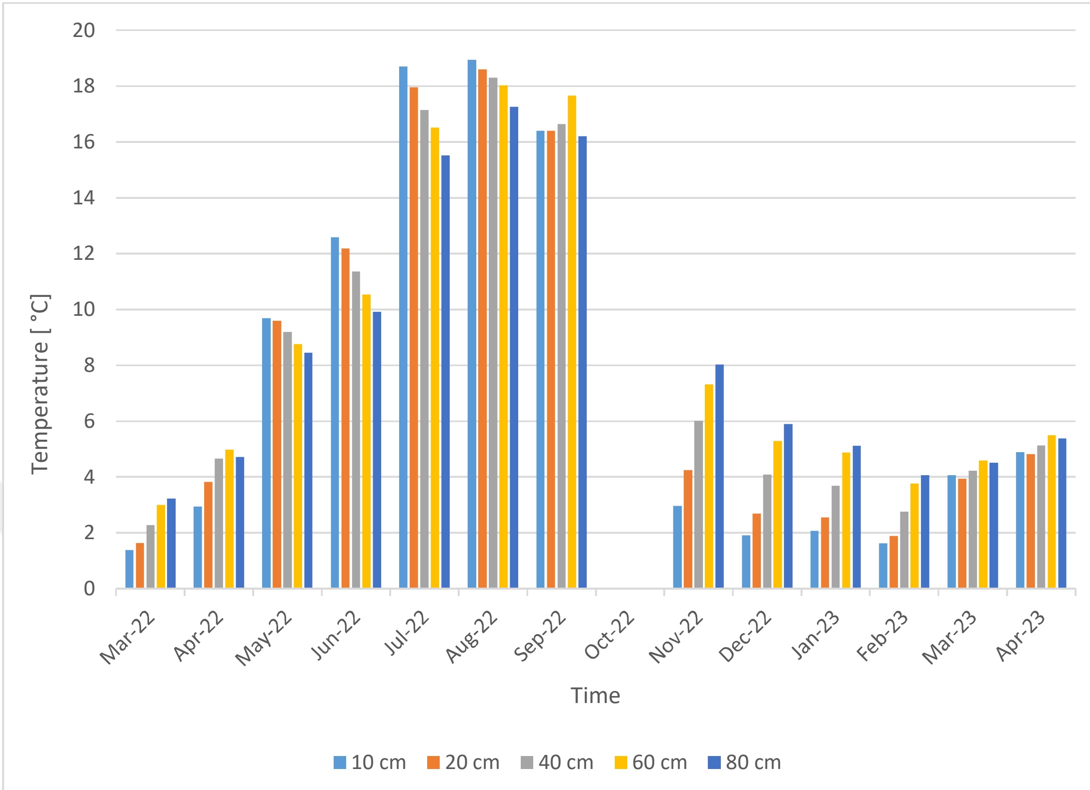

Figure 4. 5. Monthly means of temperature in the soil of meadow

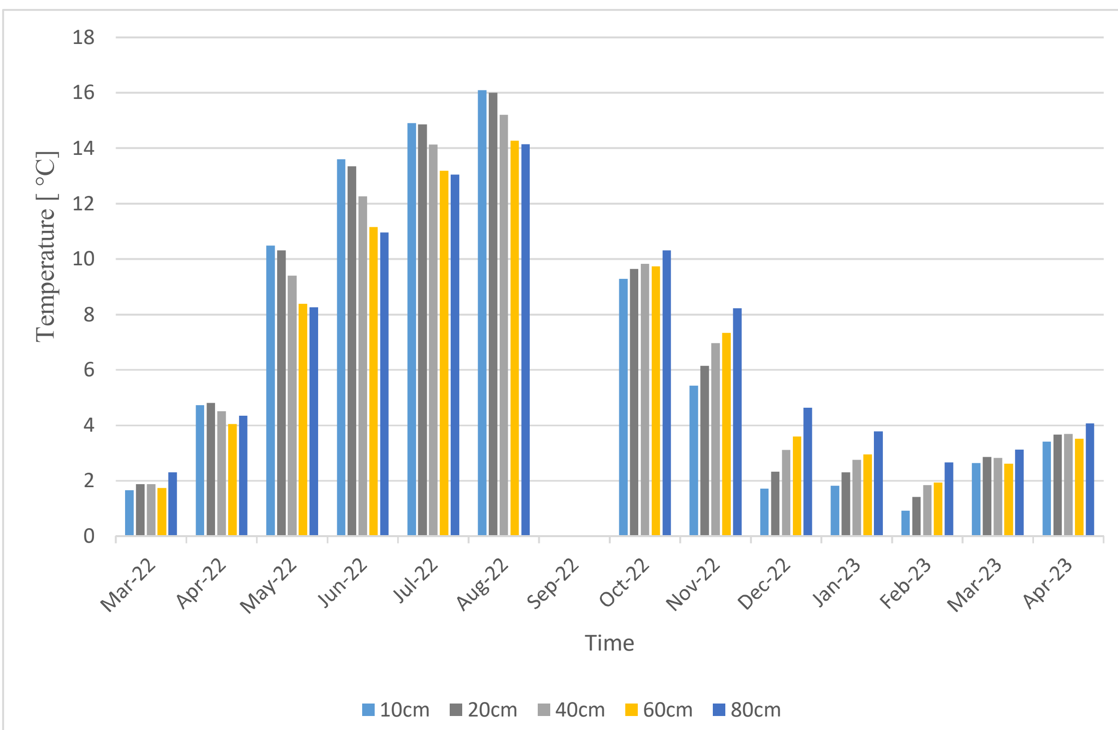

Figure 4. 6. Monthly means of temperature in the soil of forest_2

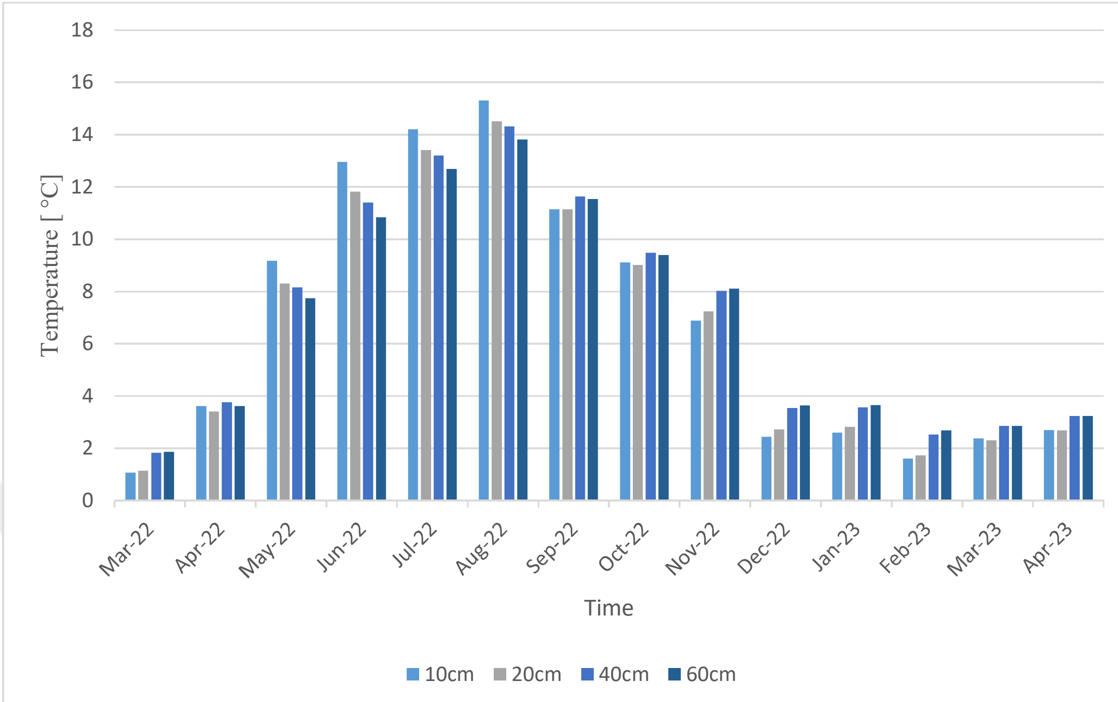

Figure 4. 7. Monthly means of temperature in the soil of south-facing forest_3

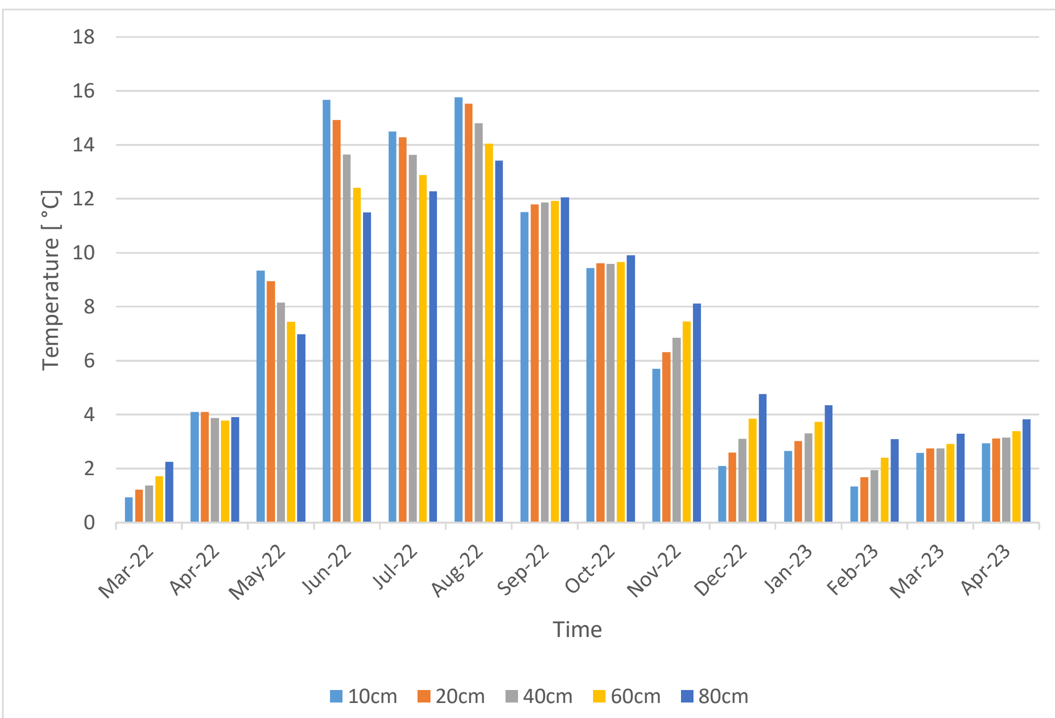

Figure 4. 8. Monthly means of temperature in the soil of north-facing forest_4

In relation to depth, soil temperature and soil depth showed a positive relation. But in the meadow temperature was the highest among the four types of land use systems which illustrated that during the winter season meadow land system would be suitable. In the depths 10cm, 20cm, 40cm, 60cm and 80 cm the average soil temperature computed for the meadow was 7.55, 7.72, 8.11, 8.52, 8.33 (°C) respectively; for forest 2, that was 6.67, 6.89, 6.80, 6.50, 6.91 °C; for forest 3, 6.79, 6.59, 6.97, 6.83, 7.00 °C; and for forest 4, that was 7.04, 7.13, 7.00, 6.97, 7.12 °C respectively. Among forest soils, highest temperature was noted in the soil of north facing forest than the soil of south facing forest;

Savva, Yulia, et al. also showed that the highest temperature was recorded during August and September in two different land types such as grassland and forest, besides, while evaluating the monthly mean of soil temperature, they found that grassland soil had 1.05 °C higher intercept than forest soil (Savva, Yulia, et al., 2010).

Seasonally, in meadow, moisture content was higher during winter season (0.43) and lower in Summer (0.17) (Figure 4.9). Moreover, there was noticeable fluctuation in the depth of soil during Summer and Autumn season compare to Spring and Winter. In forest_2, moisture content was higher during winter season (0.39) and lower in Summer (0.30) (Figure 4.10). However, fluctuation in moisture content among soil depths was noted during the summer only which was increased with depth. In the soil of forest 3, among four seasons the moisture content was higher during spring and winter, and lower in summer and autumn (Figure 4.11). All of these seasons showed variation of moisture content in different soil depth which was increased with the depths in soil profile. Moisture content was relatively lower during summer and autumn than spring and winter in the soil of forest 4 (Figure 4.12). Besides deeper layer evidenced to hold more moisture than the shallower layer.

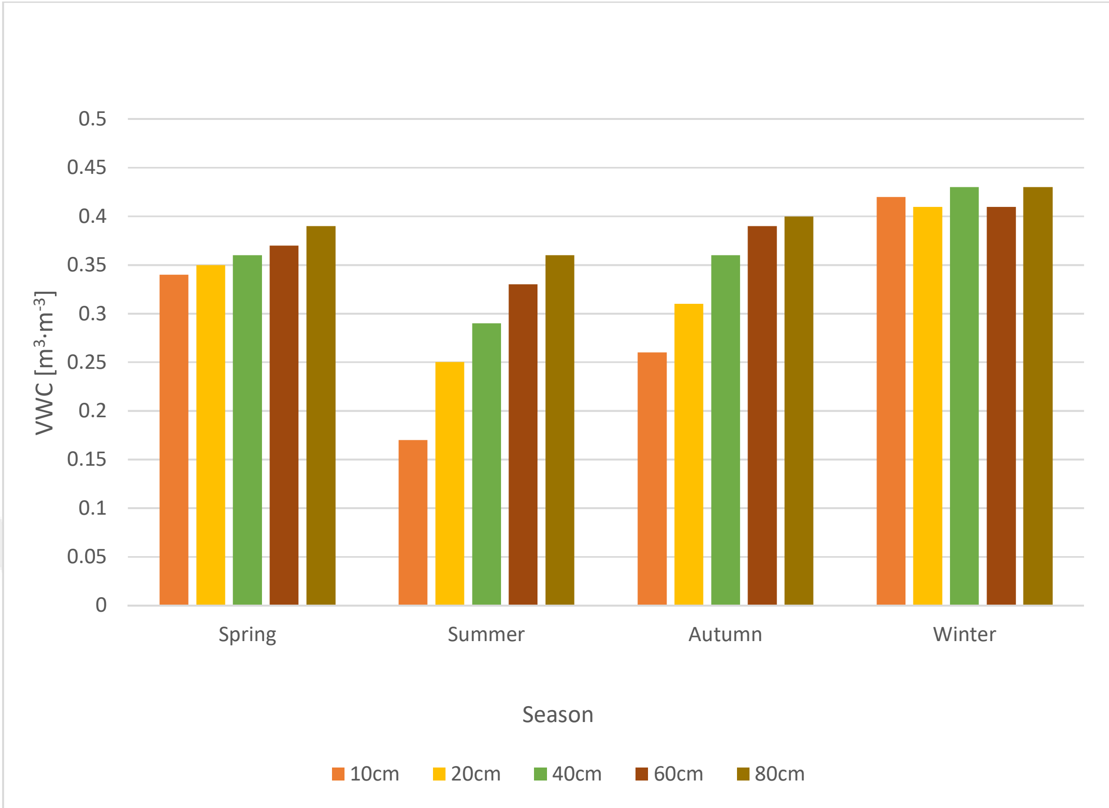

Figure 4. 9. Seasonal variation of soil moisture content in meadow

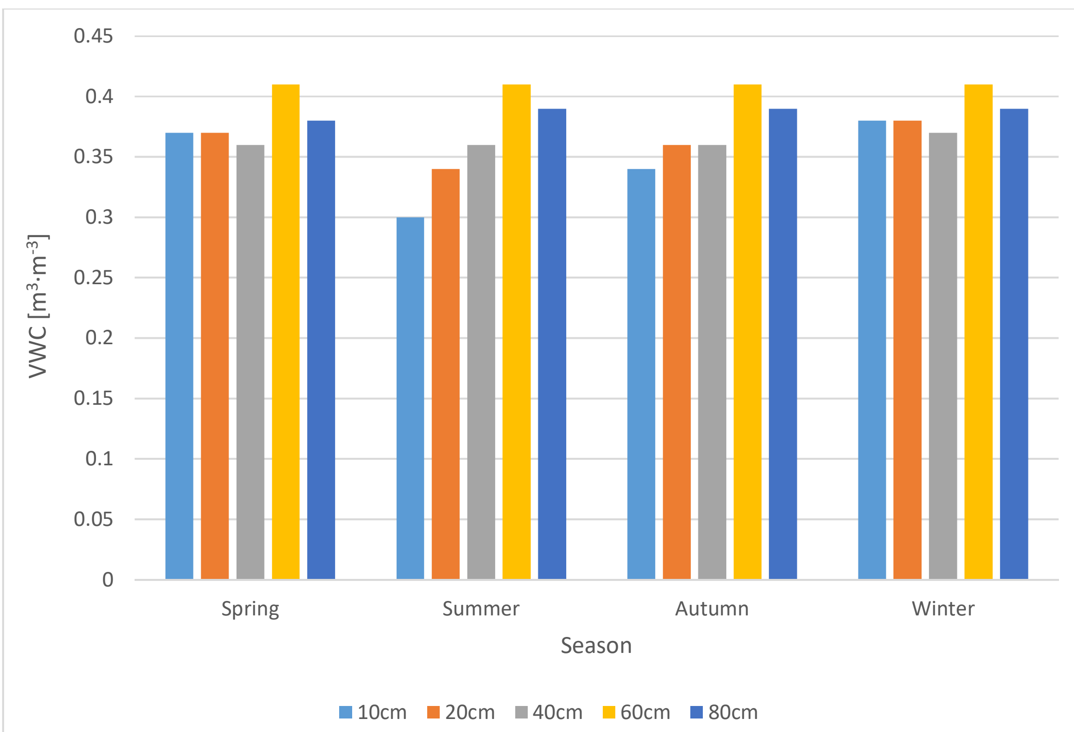

Figure 4. 10. Seasonal variation of soil moisture content in forest_2

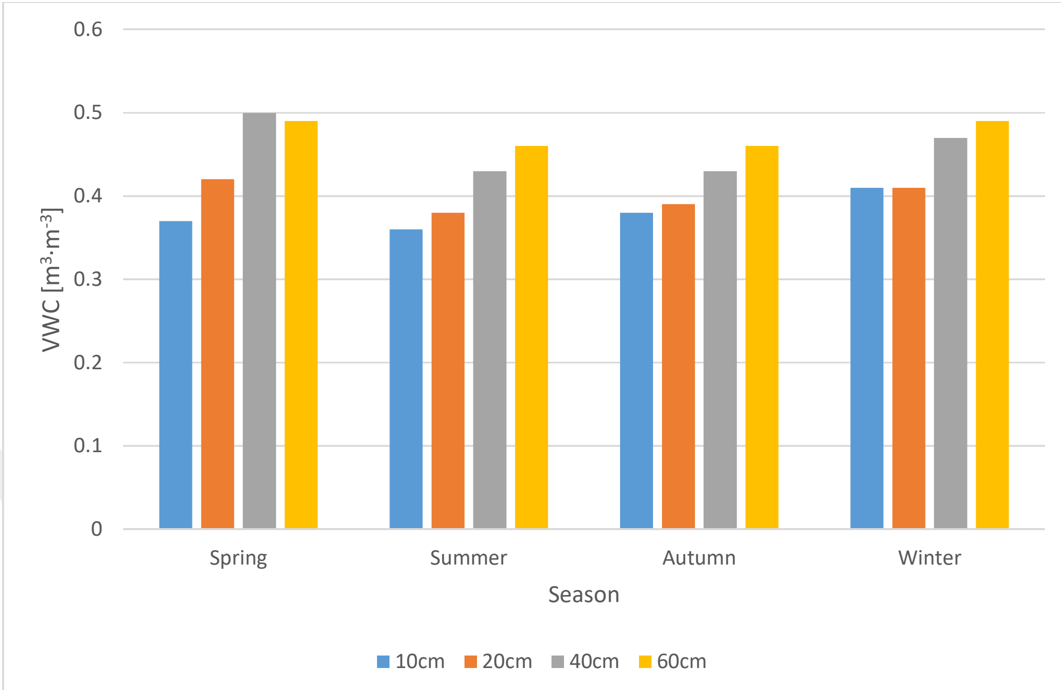

Figure 4. 11. Seasonal variation of soil moisture content in forest_3

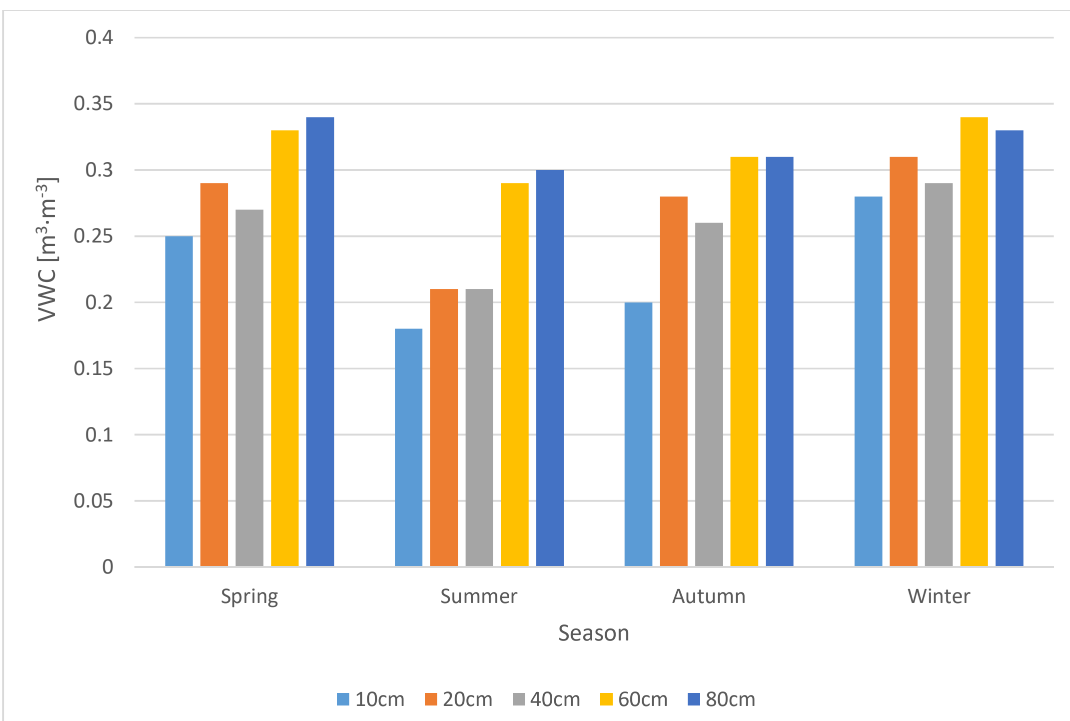

Figure 4. 12. Seasonal variation of soil moisture content in forest_4

In meadow, huge variation in temperature in different seasons can be noticed in the Figure 4.13. The highest temperature was recorded during summer from March 2022 to April 2023 which was 16.74 °C and lowest in winter season that was 1.87 °C. In addition, the variation in soil depth was noticeable during winter; temperature increased with the depth during winter and decreased during summer. In forest 2, huge variation in temperature in different seasons can be noticed (Figure 4.14). The highest temperature was recorded during summer among four seasons in a year which was 14.87 °C and lowest was in winter season that was 1.49 °C. In addition, the variation in soil depth was noticeable during winter, spring and summer; temperature increased with the depth during autumn and winter, and decreased during summer. In forest 3, the recorded temperature was much higher in summer than the other four seasons (Figure 4.15). The fluctuation of temperature was not prominent in different soil depth. The variation of temperature in different seasons and different depths is evidenced in the above figure. The highest and the lowest temperature recorded in the soil of forest 4 were 15.31°C and 2.03 °C respectively (Figure 4.16).

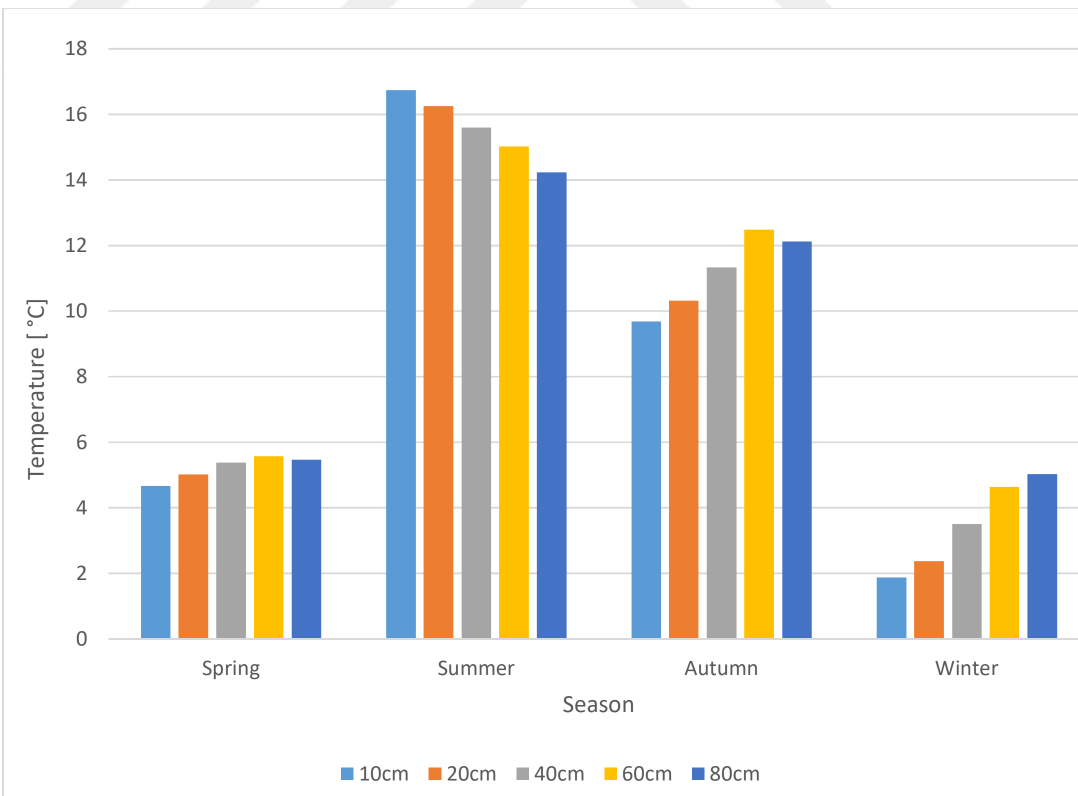

Figure 4. 13. Seasonal variation of soil temperature in meadow

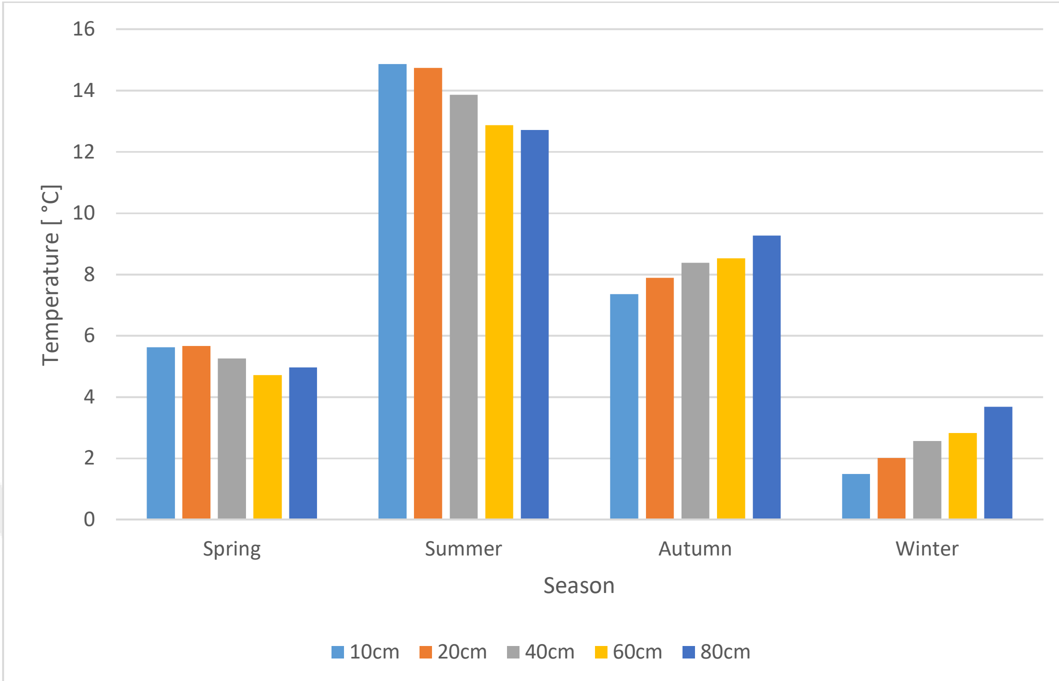

Figure 4. 14. Seasonal variation of soil temperature in forest_2

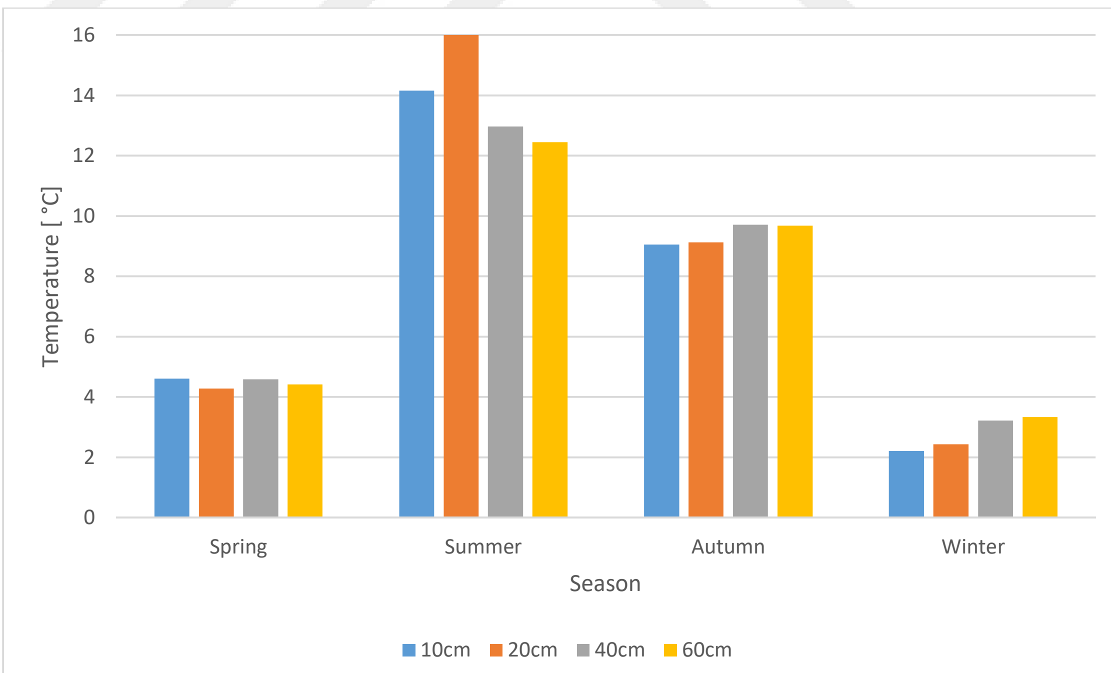

Figure 4. 15. Seasonal variation of soil temperature in forest_3

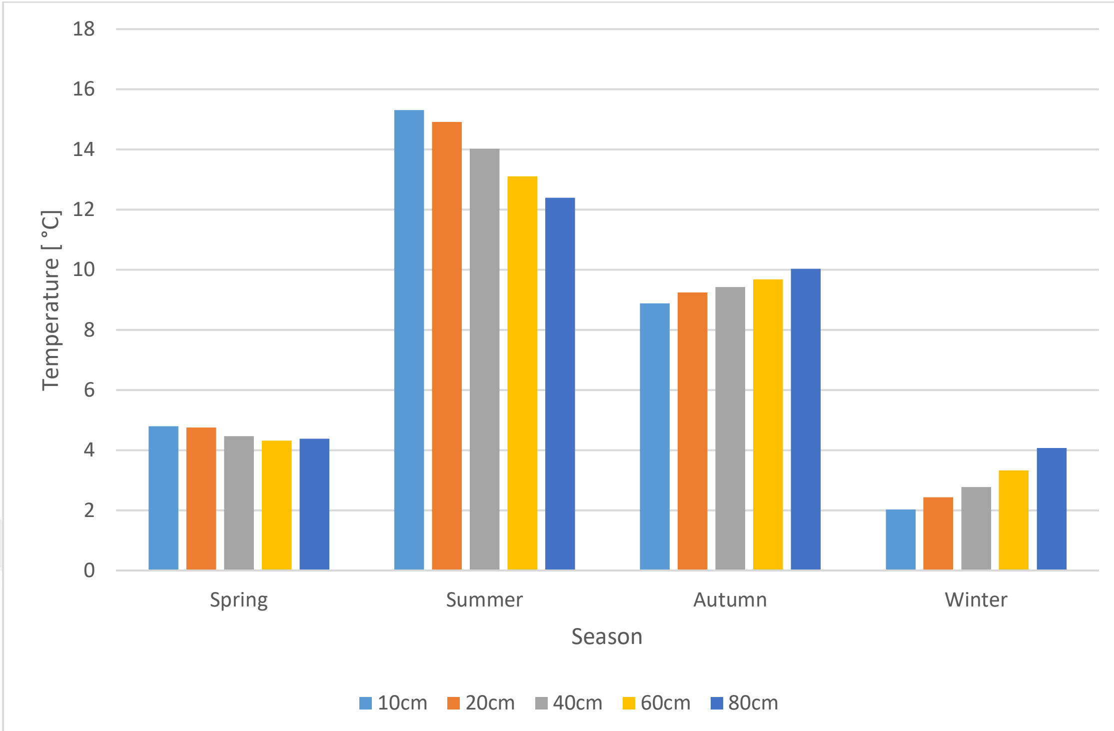

Figure 4. 16. Seasonal variation of soil temperature in forest_4

In another study, Soil respiration, soil temperature, and volumetric soil water content were measured in a balsam fir (Abies balsamea (L.) Mill.) ecosystem over a one-year period and found that soil experienced severe water stress before and during the autumn (Lavigne, et al., 2004). Temperature was noted to be increased with depth from the surface up to about 45 cm depth, then decrease and increase again with depth in the analyzed soil sample which manifested that the surface layers vary more or less according to air temperature and therefore exhibits a greater fluctuation than the subsoil (Nwankwo, et al., 2012). Soil temperature changes on a daily and annual basis affect both biological and chemical activities in the soil, such as rates of decomposition and mineralization of soil organic matter and $CO2$ emission. Soil temperature influences plant development both directly (through its effect on physiological activity) and indirectly (through its effect on soil nutrient availability) (Paul et al., 2004). In a Pinus laricio forest ecosystem of Aspromonte, southern Italy, Sidari et al., (2008) found that the soil temperature was higher on north and south-facing slope. Accordingly, the highest soil water content was on the south-facing slope.

Table 4. 4. Monthly means of soil moisture and temperature in soil _1 – meadow

Time	Depth									
	10 cm		20 cm		40 cm		60 cm		80 cm	
	moisture $m^3 \cdot m^{-3}$	°C. Temp	moisture $m^3 \cdot m^{-3}$	°C. Temp	moisture $m^3 \cdot m^{-3}$	°C. Temp	moisture $m^3 \cdot m^{-3}$	°C. Temp	moisture $m^3 \cdot m^{-3}$	°C. Temp
Mar-22	0.41	1.38	0.41	1.63	0.43	2.29	0.40	3.00	0.43	3.23
Apr-22	0.42	2.93	0.42	3.82	0.43	4.66	0.40	4.98	0.43	4.72
May-22	0.19	9.69	0.22	9.59	0.22	9.19	0.29	8.77	0.32	8.45
Jun-22	0.19	12.59	0.21	12.19	0.22	11.36	0.31	10.54	0.32	9.91
Jul-22	0.15	18.70	0.26	17.96	0.30	17.15	0.33	16.51	0.37	15.53
Aug-22	0.17	18.95	0.27	18.61	0.33	18.30	0.36	18.03	0.40	17.26
Sep-22	0.16	16.40	0.26	16.39	0.32	16.64	0.37	17.66	0.38	16.21
Nov-22	0.35	2.97	0.36	4.25	0.40	6.02	0.40	7.32	0.43	8.04
Dec-22	0.39	1.91	0.39	2.69	0.42	4.09	0.40	5.28	0.42	5.90
Jan-23	0.43	2.08	0.42	2.55	0.43	3.68	0.41	4.87	0.43	5.13
Feb-23	0.44	1.62	0.42	1.88	0.44	2.75	0.42	3.77	0.43	4.07
Mar-23	0.41	4.07	0.39	3.94	0.42	4.22	0.41	4.59	0.43	4.51
Apr-23	0.44	4.89	0.41	4.82	0.43	5.13	0.42	5.50	0.43	5.38

Table 4. 5. Monthly means of soil moisture and temperature in soil of Forest_2

Time	Depth									
	10 cm		20 cm		40 cm		60 cm		80cm	
	moisture $m^3 \cdot m^{-3}$	Temp °C	moisture $m^3 \cdot m^{-3}$	Temp °C	moisture $m^3 \cdot m^{-3}$	Temp °C	moisture $m^3 \cdot m^{-3}$	Temp °C	moisture $m^3 \cdot m^{-3}$	Temp °C
Mar 22	0.38	1.66	0.37	1.88	0.36	1.88	0.40	1.74	0.38	2.30
Apr 22	0.38	4.73	0.37	4.81	0.37	4.50	0.41	4.05	0.38	4.35
May 22	0.35	10.48	0.36	10.32	0.36	9.40	0.41	8.39	0.38	8.25
June 22	0.32	13.61	0.34	13.34	0.36	12.26	0.41	11.16	0.39	10.96
July 22	0.31	14.91	0.35	14.87	0.36	14.13	0.41	13.18	0.39	13.05
Aug 22	0.27	16.09	0.33	16.00	0.36	15.21	0.41	14.26	0.39	14.14
Oct 22	0.34	9.28	0.36	9.64	0.36	9.83	0.41	9.73	0.39	10.31
Nov 22	0.35	5.44	0.36	6.15	0.36	6.96	0.41	7.33	0.39	8.23
Dec 22	0.37	1.71	0.37	2.33	0.37	3.12	0.41	3.59	0.39	4.63
Jan 23	0.38	1.83	0.38	2.30	0.37	2.76	0.41	2.96	0.39	3.78
Feb 23	0.39	0.92	0.39	1.41	0.38	1.85	0.41	1.94	0.39	2.67
Mar 23	0.37	2.64	0.38	2.86	0.37	2.82	0.42	2.62	0.39	3.13
Apr 23	0.38	3.41	0.38	3.67	0.37	3.69	0.42	3.52	0.39	4.07

Table 4. 6. Monthly means of soil moisture and temperature in soil of Forest_3

Time	Depth									
	10 cm		20 cm		40 cm		60 cm		80 cm	
	moisture $m^3 \cdot m^{-3}$	Temp. °C	moisture $m^3 \cdot m^{-3}$	Temp °C	moisture $m^3 \cdot m^{-3}$	Temp °C	moisture $m^3 \cdot m^{-3}$	Temp °C	moisture $m^3 \cdot m^{-3}$	Temp °C
Mar-22	0.28	0.94	0.31	1.22	0.29	1.37	0.34	1.72	0.34	2.26
Apr-22	0.26	4.11	0.29	4.10	0.27	3.87	0.33	3.78	0.34	3.91
May-22	0.22	9.34	0.25	8.95	0.24	8.16	0.31	7.45	0.33	6.98
Jun-22	0.18	15.67	0.20	14.92	0.21	13.64	0.29	12.41	0.31	11.49
Jul-22	0.18	14.50	0.21	14.28	0.22	13.63	0.29	12.88	0.31	12.28
Aug-22	0.17	15.77	0.21	15.52	0.21	14.80	0.28	14.04	0.29	13.41
Sep-22	0.18	11.51	0.27	11.80	0.26	11.87	0.31	11.92	0.30	12.06
Oct-22	0.22	9.43	0.29	9.61	0.27	9.59	0.32	9.67	0.33	9.91
Nov-22	0.21	5.70	0.27	6.32	0.25	6.85	0.30	7.45	0.31	8.12
Dec-22	0.23	2.09	0.29	2.60	0.27	3.10	0.31	3.85	0.32	4.76
Jan-23	0.29	2.66	0.32	3.02	0.30	3.30	0.35	3.73	0.34	4.35
Feb-23	0.31	1.34	0.33	1.68	0.30	1.94	0.35	2.41	0.34	3.09
Mar-23	0.29	2.58	0.32	2.74	0.30	2.74	0.35	2.91	0.34	3.29
Apr-23	0.30	2.93	0.32	3.11	0.30	3.16	0.34	3.39	0.34	3.83

Table 4. 7. Monthly means of soil moisture and temperature in soil of Forest_4

Time	Depth							
	10 cm		20cm		40 cm		80 cm	
	moisture $m^3 \cdot m^{-3}$	Temp. °C	moisture $m^3 \cdot m^{-3}$	Temp. °C	moisture $m^3 \cdot m^{-3}$	Temp. °C	moisture $m^3 \cdot m^{-3}$	Temp. °C
Mar-22	0.36	1.07	0.44	1.15	0.51	1.82	0.5	1.86
Apr-22	0.38	3.61	0.42	3.4	0.51	3.76	0.5	3.62
May-22	0.36	9.16	0.39	8.3	0.49	8.16	0.49	7.74
Jun-22	0.35	12.95	0.36	11.81	0.43	11.41	0.47	10.83
Jul-22	0.37	14.21	0.39	13.42	0.44	13.2	0.46	12.69
Aug-22	0.36	15.31	0.38	14.51	0.42	14.32	0.45	13.82
Sep-22	0.36	11.15	0.38	11.15	0.43	11.63	0.44	11.54
Oct-22	0.38	9.11	0.39	9.01	0.44	9.48	0.47	9.39
Nov-22	0.38	6.89	0.39	7.23	0.44	8.03	0.47	8.12
Dec-22	0.41	2.43	0.41	2.73	0.46	3.54	0.49	3.64
Jan-23	0.41	2.6	0.41	2.82	0.47	3.56	0.49	3.65
Feb-23	0.41	1.61	0.41	1.74	0.47	2.53	0.49	2.69
Mar-23	0.4	2.38	0.41	2.31	0.47	2.86	0.48	2.84
Apr-23	0.41	2.7	0.41	2.69	0.47	3.24	0.48	3.23

5. CONCLUSION

Land use practices can impact soil moisture content and soil temperature thus affecting the availability of plant nutrients and other soil factors. Soil moisture had a negative relation with soil temperature in this study. Highest moisture and lowest temperature were noted on February in all the land systems whereas in August lowest moisture content and the highest temperature were found. In addition, seasonally also huge fluctuation was noticed in soil moisture and temperature. In the meadow ecosystem, soil temperature significantly increased from Autumn to Summer and decreased during Spring and Winter. On the other hand, moisture content has considerably risen from Spring to Winter and fallen during Autumn and Summer. In the forest systems, soil temperature was significantly higher on north-facing slope than south-facing slope and gradually decreasing from 10cm to 80cm during spring and summer season and increasing during winter and autumn season. On contrary, during winter the temperature of upper horizon was very low and increase gradually as going deeper in the soil profile. Furthermore, the study revealed that north-facing slopes in the forest systems had higher soil temperatures, while south-facing slopes consistently had higher soil moisture. The upper horizon of soil profile has a high fluctuation of soil temperature and water content than the lower horizons. Furthermore, soil moisture content and soil temperature evidenced a linear relationship with depth in the soil profile in all the land systems.

Further research is required to investigate the other factors responsible for the variation in moisture and temperature resulting in the study soils of four areas.

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