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Fluctuations in Soil Temperature and Moisture in Various Types of Agricultural Land Use: Implications of Soil Physical Properties

Fluktuasi Suhu dan Kelembaban Tanah pada Berbagai Tipe Penggunaan Lahan Pertanian: Implikasi Sifat Fisik Tanah

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ABSTRACT

Climate change impacts all aspects of life including agriculture, which influences land management practices, soil temperature and moisture, and land use types. This research aims to identify soil temperature and moisture fluctuations across various agricultural land cover types and their relationship to soil physical properties. This research was conducted in Mariat District, Sorong Regency, on four types of land use and was selected intentionally (purposive sampling). The coordinates of each type of land are: Rice Field 075°77’35’’E 98°88’12”SL; Garden land: 075°75’82”E, 98°88’09”SL; Agroforestry land: 075°74’30”E, 98°88’01”SL; and Unproductive land 075°76’30”E, 98°88’80”SL. Measurement of soil temperature and humidity using environment-meter for 30 consecutive days and soil sampling was carried out (intact soil samples and disturbed soil samples) to identify the physical properties of the soil. The research results showed fluctuations in soil temperature and moisture content across each land use. In general, the average morning temperature was 27.2°C, midday 32°C, and evening 27.5°C. Meanwhile, the average soil moisture content was 79.5% in the morning, 74% in the afternoon, and 81% in the evening. The physical properties of the soil in the four land uses are different in soil texture, soil color, available water, permeability, and aggregate stability. The use of rice fields and dry fields has the same temperature and humidity. However, the use of gardens and agroforestry land tends to differ because variations influence plant vegetation. Temperatures too high and humidity too low can worsen soil conditions, causing physical degradation that affects agricultural productivity and soil sustainability.

Keywords: fluctuation; soil physics; moisture; temperature; land use.

ABSTRAK

Perubahan cuaca berdampak pada segala aspek kehidupan, salah satunya pada bidang pertanian, yang mempengaruhi praktik pengelolaan lahan termasuk suhu dan kelembaban tanah terhadap tipe penggunaan lahan. Tujuan penelitian adalah mengidentifikasi fluktuasi suhu dan kelembaban tanah pada berbagai tipe tutupan lahan pertanian yang berkaitan dengan sifat-sifat fisik tanah. Penelitian ini dilakukan di Distrik Mariat, Kabupaten Sorong, pada 4 jenis penggunaan lahan dan dipilih secara sengaja (purposive sampling) yaitu Lahan Sawah: 075˚77’35’’ BT 98˚88’12” LS Lahan Kebun: 075˚75’82” BT, 98˚88’09” LS; Lahan Agroforestri: 075˚74’30” BT, 98˚88’01” LS; dan Lahan Tegalan 075˚76’30” BT, 98˚88’80” BT. Pengukuran suhu dan kelembaban tanah menggunakan environment-meter selama 30 hari berturut-turut dan dilakukan pengambilan sampel tanah (sampel tanah utuh dan sampel tanah terganggu) untuk mengidentifikasi sifat-sifat fisik tanah. Hasil penelitian menunjukkan terjadi fluktuasi suhu dan kelembaban tanah pada masing-masing penggunaan lahan. Secara umum rata-rata suhu pada pagi hari yaitu 27,2 °C, siang hari 32 °C, dan sore hari 27,5 °C, sementara rata-rata kelembaban tanah pada pagi hari yaitu 79,5 %, siang *hari 74 %, dan sore hari 81 %. Sifat fisik tanah pada empat penggunaan lahan yaitu memiliki perbedaan pada tekstur tanah, warna tanah, air tersedia, permeabilitas, dan stabilitas agregat. Penggunaan lahan sawah dan tegalan memiliki suhu dan kelembaban yang sama, namun pada penggunaan lahan kebun dan agroforestri cenderung berbeda karena dipengaruhi oleh variasi vegetasi tanaman. Suhu yang terlalu tinggi dan kelembaban yang terlalu rendah dapat memperburuk kondisi tanah, menyebabkan degradasi fisik yang mempengaruhi produktivitas pertanian dan keberlanjutan tanah.*

Kata kunci: ***fluktuasi; fisik tanah; kelembaban; suhu; penggunaan lahan.***

I. INTRODUCTION

Climate change has always been an endless topic of global discussion, especially about agriculture ((Tomasek, et al., 2017). The impact of climate change on agriculture has become evident with the shift in rainfall patterns, increased frequency of extreme weather events, and changes in planting seasons (Hidayati & Suryanto, 2015; Muslim, 2013; Papadopoulou et al., 2020). These challenges include feeding the continuously growing global population while ensuring environmental sustainability and adapting to changing weather patterns. FAO reports that the world's population will reach 9.73 billion by 2050, and this increase will continue until it reaches 11.2 billion by 2100 (Godoy et al., 2014). There is a need to increase agricultural production and productivity to ensure sufficient amounts for the growing population (Fischer et al., 2014; Tilman et al., 2011) and to meet the food needs of 10 billion people by 2050 (Godoy et al., 2014). While most farmers are engaged in small-scale rainfed agriculture, its success influenced by their ability to adjust agricultural practice decisions to prevailing weather conditions (Osborne and Wheeler 2013).

Soil temperature and moisture are important factors in agricultural land cover because they directly affect plant growth and productivity (Thoriq et al., 2022). Measuring soil temperature and moisture is important for agriculture because it can provide early drought warnings. Soil temperature and moisture play an important role in vegetation growth, ecosystems, the water cycle, and climate change (Zhu et al., 2019). The condition of soil moisture is influenced by temperature because there is a water and energy flux at the atmosphere-soil surface through evapotranspiration. The soil moisture conditions change in agricultural land must be monitored to determine whether they are too dry or very wet. It is crucial for optimizing agricultural production and implementing effective agricultural management practices (Said et al. 2021).

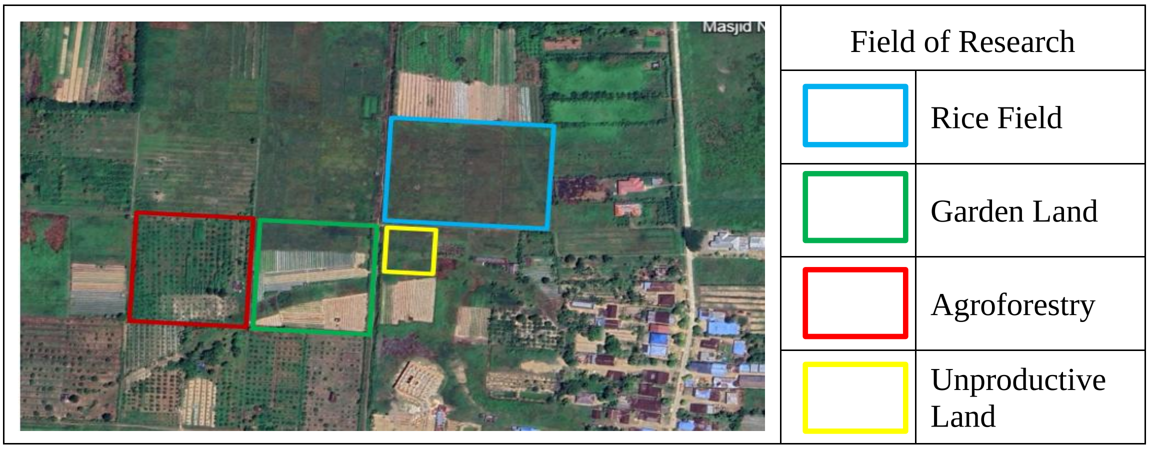
Understanding soil temperature and moisture dynamics is not only essential at the global or theoretical level but also highly relevant when applied to specific local contexts. Each region possesses unique environmental and land-use characteristics that influence soil conditions and agricultural productivity (Semin & Namyatova, 2019). Therefore, studying these parameters at the regional scale can provide more accurate information for developing effective agricultural management strategies (Xie et al., 2015). In this regard, examining soil temperature and moisture variations in local agricultural areas such as Mariat District becomes crucial to understanding how land cover and management practices affect soil health and crop performance.

Mariat District is one of the districts in Sorong Regency with the highest population, approximately 17,449 people, which has increased by 0.019% from 2018 to 2022 (BPS, 2023). Mariat District has a relatively high agricultural potential with an agricultural land area of 14,914.0 hectares (RPD, 2023). However, data obtained from the Sorong Regency Agriculture Office shows that land use for crop cultivation activities is not fully optimized (Ali, A, et al., 2021). Soil temperature and humidity across different land covers are vital, as they influence water and nutrient availability, plant growth, fertilization, irrigation, and overall land productivity. The function of the soil will be able to work optimally if the soil potential factors and physical soil conditions are considered (Riskawati, R, et al 2021). Thus, this research aims to identify fluctuations in soil temperature and moisture across various agricultural land cover types and examine the soil's physical properties.

II. RESEARCH METHODS

1. Time and Location

The research was conducted from August to October 2024. The research location was deliberately selected (purposive sampling). The selection of these locations was determined because the Mariat District has a variety of agricultural land cover types practiced by local farmers. The research location is a rainfed agricultural land (suboptimal dry land) where several types of agricultural land cover were chosen in the Mariat District, Aimas Sub-district, Southwest Papua. The coordinates of each type of land are: Rice Field 075°77'35''E 98°88'12"SL; Garden land: 075°75'82"E, 98°88'09"SL; Agroforestry land: 075°74'30"E, 98°88'01"SL; and Unproductive land 075°76'30"E, 98°88'80"SL.



Source: Google Earth

Figure 1. The Research Location

2. Soil Sampling

The soil samples consist of disturbed and undisturbed to determine the characteristics of soil physical properties for each type of land use. Disturbed soil were taken with a shovel, approximately 500 g at 0-20 cm depth for each type of agricultural land use. Subsequently, undisturbed soil were taken using a sampling ring for each land cover type. Subsequently, the analysis of soil samples was conducted at the Soil Chemistry and Fertility Laboratory, Department of Soil Science, Faculty of Agriculture, Hasanuddin University. The purpose of analyzing disturbed and undisturbed soil sample is shown in Table 1.

Table 1. Soil physical properties for laboratory analysis:

No	Physical Properties of Soil	Unit	Method
1	Soil texture	-	Hidrometer/pipet
2	Bulk density	g/cm^{-3}	Gravimetri (ring sample)
3	Porosity	%	Gravimetri (ring sample)
4	Avalaible water capacity	%	Gravimetri (pressure plate aparatus)
5	Permeability	cm/jam	Constant head
6	Aggregate Stability	-	Dry Sieving
7	Soil color (wet and dry)	-	Munsell soil colour chart

Source: (Grzywna & Ciosmak, 2021; Riskawati et al., 2021)

3. Measurement of soil temperature and soil moisture

The method of measuring soil temperature and humidity or moisture is carried out by inserting the tip of the Environment meter sensor into the soil. Data collection of soil temperature and moisture at a depth of 0-20 cm for each type of agricultural land cover is done with 3 repetitions in 30 days. Data collection was conducted three times a day, in the morning (06:00-07:00 WITA), afternoon (12:00-13:00 WITA), and evening (17:00-18:00 WITA) for 30 consecutive days.

4. Analysis and Data Processing

The analysis and processing of daily soil temperature and humidity data are calculated using formula I (Sabaruddin L., 2012):

$$\text{T daily} = \frac{\text{2T morning} + \text{T afternoon} + \text{T evening}}{4} \quad \text{…………………..…………(1)}$$

T average is daily soil temperature; T morning is soil temperature during morning measurements; T afternoon is soil temperature during daytime measurements; and T evening was soil temperature during the afternoon measurement.

$$\text{RH daily} = \frac{\text{2 RH morning} + \text{RH afternoon} + \text{RH evening}}{4} \quad \text{……………………..(2)}$$

RH average is daily soil moisture; RH Morning is soil moisture in the morning measurement; RH afternoon is soil moisture during daytime measurements; and RH evening was soil moisture in the afternoon measurement.

III. RESULTS AND DISCUSSION

1. Soil temperature

The fluctuation of soil temperature in various land use types showed significant differences, as seen from the measurement results of soil temperature in the morning, afternoon, and evening. Over 30 days or 1 month of observation, the temperature fluctuations very throughout the day. The average soil temperature for each land use showed Table 2.

For each type of land use, the temperature in the afternoon is much higher compared to the morning and evening temperatures. There is a significant temperature increase due to the greater radiation received (Pandoh, N, et al., 2021).

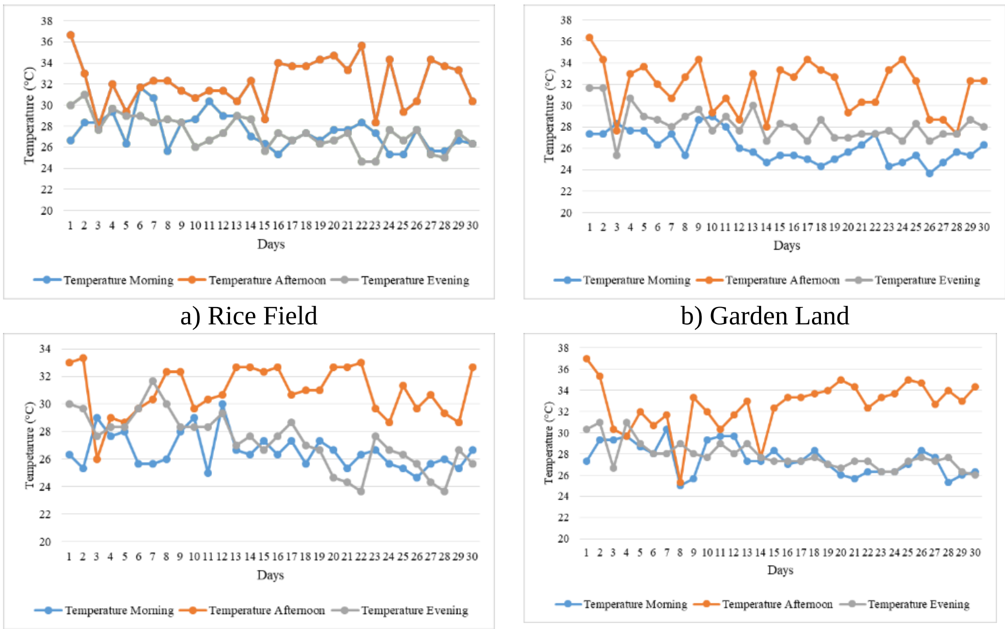
Each land use type has distinct characteristics and purposes based on its management goals. Rice fields are designated for rice cultivation using flooded or intermittent irrigation, serving as a key source of staple food and supporting ecosystem balance through controlled water management (He et al., 2020). Gardens are planted with seasonal or perennial crops like fruits, vegetables, or plantations and are intensively managed to produce high-value commodities that boost local income (Lovell, 2010; Tresch et al., 2018). Agroforestry integrates trees and agricultural crops within the same area, providing both timber and food while offering ecological benefits (Mosquera-Losada et al., 2018). Non-productive land is refers to barren or abandoned areas lacking rehabilitation, resulting in low economic and ecological value (Šalkauskienė et al., 2019). Average soil temperature for each land use are shown in Table 2.

Table 2. Average soil temperature for each land use

Time period	Average soil temperature for each land use (°C)				General Average (°C)
	Rice field	Garden	Agroforestry	Unproductive land	
Morning	28	26	27	28	27,2
Afternoon	32	32	31	33	32
Evening	27	28	27	28	27,5

Rice fields that remain waterlogged show a distinct soil temperature pattern. In the morning, soil temperature is lower as heat is released overnight. Waterlogged soil helps maintain temperature stability and slows the increase in soil temperature (He et al., 2020). At the study site, temperatures increased by about 4°C from morning to afternoon (Table 2; Figure 2) due to stronger sunlight. However, this rise is more moderate than in unproductive land, and by afternoon, soil temperature gradually decreases without a sharp drop.

Soil temperature measurements in the garden indicate cooler conditions in the morning after nighttime heat loss, averaging 26°C in the morning, 32°C in the afternoon, and 28°C in the evening. Afternoon temperatures rise sharply by about 6°C due to sunlight, then drop by 1–4°C in the evening. Vegetation helps stabilize temperature; in this study, the garden with long bean plants and no mulch showed faster heating than gardens with taller plants or mulch cover. Several studies have shown that conservation tillage with mulch can reduce soil temperature by 1.5°C–1.8°C in the spring and improve soil penetration resistance (Blanco-Canqui & Ruis, 2018; Chen et al., 2021; Li et al., 2022; Shen et al., 2018). Garden lands with various types of horticultural plants tend to have fluctuations in soil temperature influenced by vegetation cover, mulch management, and irrigation levels. Agroforestry land demonstrates that diverse vegetation and canopy cover help lower soil temperature. In the morning, the soil remains cooler because trees slow heat release during the night. Throughout the day, temperature increases are minimal only about 4°C since tree shade limits direct solar radiation. By afternoon, soil temperature drops again as vegetation and organic litter on the surface further reduce heat compared to open land.



a) Rice Field b) Garden Land

c) Agroforestry d) Unproductive Land

Figure 2. Fluctuations in soil temperature based on daily measurement for each land use

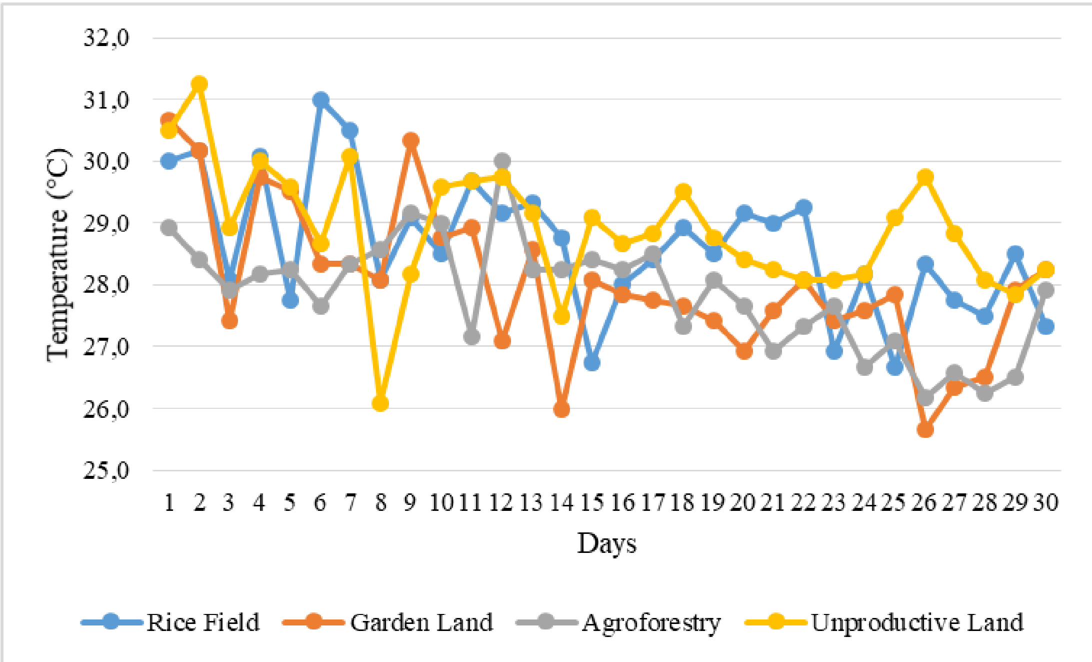


Figure 3. Daily soil temperature fluctuations in each land use type

Soil temperature in unproductive land exhibit higher temperature fluctuations throughout the day. From day 5 to day 30, there is a significant difference compared to other land uses. In the morning, field soil temperature is relatively low, averaging around 28°C, after losing heat overnight. From morning to noon, temperatures on unproductive land rise rapidly by about 8°C due to minimal grass cover that allows quick heat absorption. During the afternoon, temperatures drop sharply again as the exposed soil releases heat quickly, showing greater daily fluctuations than vegetated areas.

Soil temperature fluctuations in garden and agroforestry are very different from those in rice fields and unproductive land (Figure 3). Soil temperature throughout the day highly depends on the type of land use. This can be seen in the differences in average soil temperature for each land uses (Table 1). Flooded rice fields have the most stable temperature fluctuations due to the role of water as a heat buffer. Garden land depends on the type of plants and management, with mulch playing an important role in stabilizing soil temperature. Agroforestry produces cooler and more stable soil temperatures thanks to the protection of vegetation. Conversely, fields with minimal shade have the highest temperature fluctuations.

2. Soil Moisture

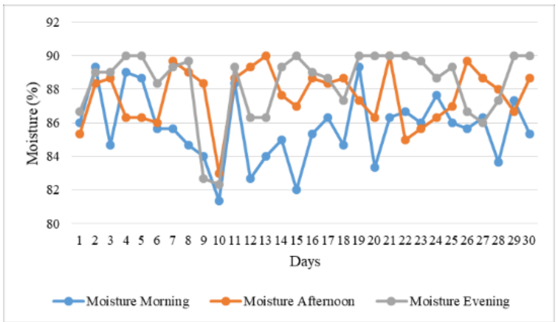
The fluctuations in soil moisture across 4 types of land use show differences, as evidenced by the measurements indicating that rice fields and unproductive land have similar moisture fluctuations, while garden and agroforestry land use tends to differ.

Table 3. Average soil moisture for each land use

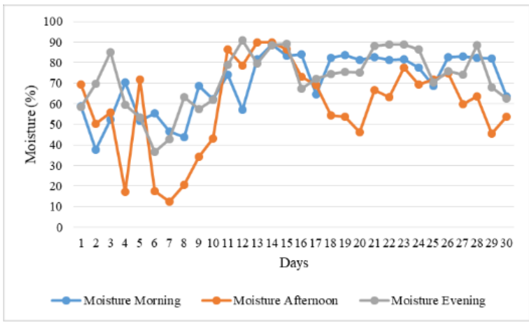
Time period	Average soil moisture for each land use (%)				General Average (%)
	Rice field	Garden	Agroforestry	Unproductive land	
Morning	86	70	76	86	79,5
Afternoon	88	59	63	88	74
Evening	88	72	76	88	81

The average soil moisture in rice fields in the morning is 86%, in the afternoon 88%, and in the evening 88% (Table 3; Figure 5). Rice fields, which are generally flooded with water, cause more stable soil moisture compared to other types of land. Waterlogging plays an important role in regulating soil moisture throughout the day. In the morning, soil moisture in rice fields is generally still high, especially if the fields have been flooded overnight. In the afternoon, although strong evaporation occurs from sunlight, soil moisture in rice fields stays more stable than in non-flooded areas. Surface water evaporation helps maintain consistent moisture levels, with only a slight decrease. As sunlight intensity lessens later in the day, soil moisture in rice fields tends to rise or stabilize again, supported by irrigation or remaining standing water. The soil moisture in rice fields with flooded irrigation tends to be more stable with minimal daily fluctuations, because this irrigation system effectively controls soil moisture compared to dry agricultural land (Zhang, et al., 2018).

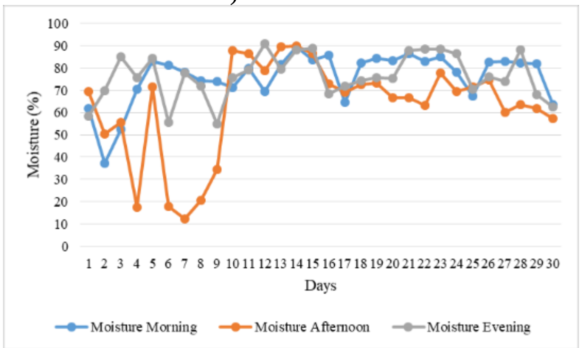
The average soil moisture in garden land varies 70% in the morning, 59% in the afternoon, and 72% in the evening (Table 3; Figure 5). This fluctuation occurs because garden soil is more prone to evaporation. Moisture is highest in the morning when soil temperatures are low and evaporation is minimal. Then in the afternoon, soil moisture tends to decrease rapidly due to high evaporation, especially if the garden land lacks adequate soil cover (mulch) (Van Dung et al., 2022). Garden land dries quickly, especially in the dry season or with limited irrigation. In the afternoon, moisture slightly rises as sunlight intensity decreases, particularly if irrigation is provided. Without it, moisture remains low. According to Alskaf et al. (2021) noted that gardens lacking vegetation or mulch experience strong moisture fluctuations, with significant daytime declines caused by high evaporation.



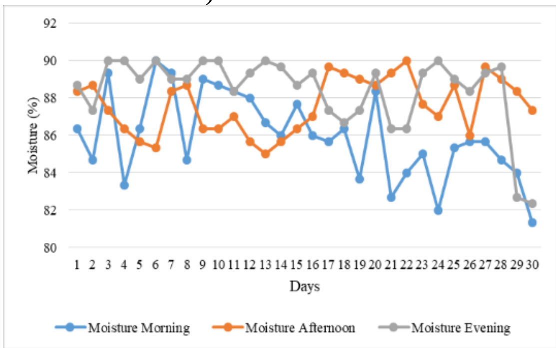
a) Rice Field



b) Garden Land



c) Agroforestry



d) Unproductive Land

Figure 4. Fluctuations in soil moisture based on daily measurement time for each land use

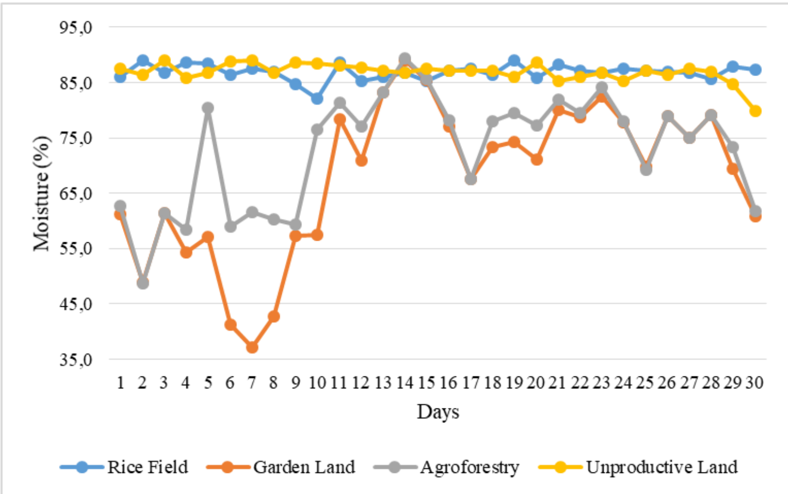


Figure 5. Daily soil moisture fluctuations in each land use type

Agroforestry land has an average soil moisture of 76% in the morning, 63% in the afternoon, and 76% in the evening (Table 3; Figure 5). The moisture is still considered suitable for supporting plant growth. It is in line with the opinion that the optimal soil moisture for some types of plants ranges from 50% to 70% (Wang et al., 2024). In the morning, soil moisture in agroforestry land is relatively high because tree cover helps retain nighttime moisture and reduces evaporation. During the day, shade from trees limits water loss, keeping soil moisture higher than in open fields. In the afternoon, moisture remains stable or slightly increases with dew. Overall, agroforestry systems maintain more stable soil moisture and smaller daily fluctuations than monoculture farming (Salem, et al., 2021).

The average soil moisture on unproductive land reaches 86% in the morning, 88% in the afternoon, and 88% in the evening (Table 3; Figure 5). This value is comparable to that found in rice fields. Such similarity may occur because in flooded rice fields, evaporation rates are high, yet transpiration remains low due to the dominance of rice plants. Conversely, in unproductive areas with sparse vegetation, evaporation can increase; however, when surface water is available, soil moisture stays elevated. These high moisture values are influenced by minimal plant cover and limited land management. Consequently, the soil becomes more responsive to humidity fluctuations throughout the day. Since the research site had been left uncultivated for a long period, its soil retained relatively high moisture levels. Morning moisture tends to be higher due to dew absorption, yet it diminishes quickly as sunlight increases and vegetation cover is lacking. Generally, soil moisture decreases sharply during the day, especially in the dry season or when rainfall is absent. According to Zhang et al. (2022) found that terraced land shows similar daily moisture declines due to sparse vegetation and low maintenance. Overall, rice fields and unproductive land have comparable moisture levels, while garden and agroforestry areas show more variation yet remain suitable for cultivation.

Temperature and soil moisture on agricultural land have an inverse relationship when temperature rises, humidity decreases, and the opposite also applies. These two factors significantly affect plant growth and require careful management. Likewise, insufficient humidity leads to dehydration, whereas excessive moisture encourages fungal and bacterial infections that harm crops. Soil moisture is also a key factor that affects soil heat flow, growth, and yield (Chen et al., 2021). Rainfall primarily influences soil moisture in non-irrigated areas, and higher moisture during the rainy season supports better water and nutrient absorption, improving plant growth and yields (Wang et al., 2024).

3. The relationship between soil temperature and moisture and the physical properties of soil

Generally, the soil physical properties for each land use (Table 4) showed that there is a relationship between the soil physical properties and soil temperature and moisture. Based on the texture class of each land use type, the texture falls into the moderate to outstanding category (Riskawati et al., 2021). Soil texture is a fundamental physical characteristic of soil that is difficult to change and takes a long time (Fu et al., 2022). The dominant soil texture at the research location is silty clay and clay. It supports the notion that the land at the research location is very suitable for agricultural development because, according to Hardjowigeno & Widiatmaka (2017), clay-textured soil is suitable for agricultural land development. Next, the soil color shows that the use of rice fields, gardens, and agroforestry has the same color with a YR (Yellow-Red) chroma but with different values and hues. Meanwhile, on the dryland fields, there is a significant difference between the color of wet soil and dry soil.

High soil moisture tends to reduce or hold back the increase in soil temperature; conversely, very dry soil heats up quickly and the surface temperature is higher. In rice fields, soil properties such as dominant dust/silt texture plus a little clay so that the texture is relatively fine compared to sand; BD ~1.20 (quite low) so sufficient porosity. With relatively high permeability (9.6 cm/hour) but because rice fields are usually irrigated, soil moisture conditions are likely high and water retention is good. then soil moisture in rice fields will be quite high and stable, so that soil temperature will tend to fluctuate less, because water is abundant and the cooling effect (evaporation / heat capacity) applies. In garden land, the texture is slightly more clay (32%) than in rice fields (12%). BD is slightly higher (1.21 vs 1.20) but generally similar. AWC is slightly higher. Soil moisture can be slightly higher than in rice fields, water retention is better (because there is more clay) so soil temperature can be slightly more stable or fluctuate less than in land with a coarser texture. In agroforestry land the fraction of soil texture is sand 23%, dust 62%, clay 16% which means slightly finer texture than rice fields and gardens; lowest BD (1.19) highest porosity among the four lands. Lower permeability (7.0 cm/hour) means water outflow is slower, water retention is better. then soil moisture is high and very stable indicated soil temperature tends to fluctuate the least and its increase is most dampened. Because unproductive land showed the lowest permeability (6.4 cm/h) and highest AWC (64), we infer that its soil moisture was maintained at a high level, thus dampening temperature fluctuations in the subsurface.

Table 4. Results of analysis of soil physical properties for each type of land use

Land Use Type	Soil physical properties											
	Soil Texture (%)			Class of texture	Soil Colour		BD	PD	Po (gr/cm^3)	AWC	Permeabilty (cm/jam)	AS
	Sand	Dust	Clay		Moist	Dry	(gr/cm^3)					
Rice field	17	71	12	Dusty clay	10 YR 7/2	10 YR 9/2	1.20	2.51	52	9.6	1.98	45
Garden Land	23	45	32	Dusty clay	10 YR 5/2	10 YR 9/1	1.21	2.61	54	10.2	5.41	55
Agroforestry	23	62	16	Clay loam	10 YR 4/2	10 YR 9/4	1.19	2.58	54	7.0	2.63	68
Unproductive land	23	57	20	Dusty clay	5 YR 9/1	7,5 YR 7/2	1.19	2.55	53	6.4	2.67	40

Note: S: Sand; D: Dust; C: Clay; BD: Bulk Density; PD: Particle Density; Po: Porosity; AWC: Avalaible Water Capasity; AS: Aggregate Stabilty

Research shows that high soil temperatures can reduce soil moisture levels, which affects soil density. Dry soil tends to be denser due to the shrinkage of soil pores, reducing the soil's ability to absorb and retain water. Bulk density in the four types of land use does not show significant differences. Particle density is still considered normal for mineral soil. Meanwhile, intensive maintenance makes more water available in the garden. The small soil pores will lower permeability as water flows more slowly. Soil dominated by sand has high permeability, whereas if the soil texture is clay, it has low permeability. Then, extreme soil temperatures (either too high or too low) can affect the process of soil particle binding and influence soil permeability (Stockstad et al., 2022).

Higher soil temperatures can speed up the decomposition of organic matter, influencing soil aggregate formation. Stable aggregates are essential for preserving soil porosity and its capacity to hold water and air. Prolonged high temperatures can also reduce organic matter content, weaken soil structure, and reduce soil aggregate stability (Islam et al., 2021). Soil temperature also affects the rate of water infiltration into the soil. Higher temperatures cause faster evaporation of soil water, leading to drier soil and increased resistance to water infiltration. In extreme heat conditions, low-moisture soil can harden and form a crust on the surface, reducing the ability of water to seep into the soil (Azmi, 2019; Van Dung et al., 2022; Wang et al., 2024).

IV. CONCLUSION

The average temperature in morning was 27.2°C, afternoon 32°C, and evening 27.5°C. Meanwhile, the average soil moisture content was 79.5% in the morning, 74% in the afternoon, and 81% in the evening. Soil temperature varies by land use type. Flooded rice fields have the most stable temperatures due to water's heat-buffering effect. Gardens depend on crop type and mulching for stability, while agroforestry remains cooler from dense vegetation. In contrast, open fields with little shade experience the greatest temperature fluctuations. Soil moisture in four types of land use shows that rice fields and unproductive land tend to have similar moisture levels, unlike garden and agroforestry land use, which appear more varied but are still in good condition for land processing. Soil temperature and moisture directly affect the physical properties of the soil.

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