2025 IVSS

Investigation of Factors Affecting Soil Temperature and Its Impact on Plant Growth

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I. Abstract

This study aims to explore the impact of different weather factors, years, and latitudes on soil temperature, as well as whether soil temperature affects crop growth. We found that air temperature is closely related to soil temperature, and the differences between years are also linked to air temperature, which can be traced back to the influence of various meteorological factors. Regions with similar latitudes tend to have comparable soil temperature changes, which are associated with local climate and soil properties. Furthermore, the experiment revealed that soil temperature has a significant effect on the growth of mung beans, and controlling the temperature can stabilize plant growth.

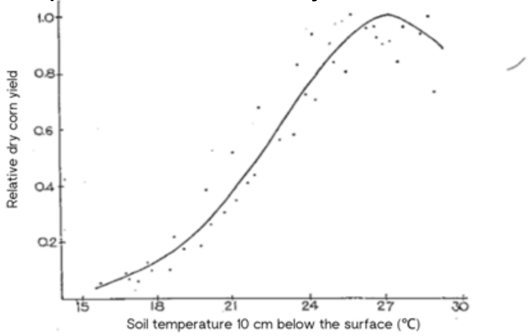
II. Motivation and Objective

Soil temperature influences plant growth and ecological stability. Various factors contribute to soil temperature changes. This study aims to explore the relationship between soil temperature and weather factors such as air temperature and humidity, as well as human activities, to gain deeper insights into the impact of climate change on the environment and agriculture. The research will examine multiple meteorological factors, including precipitation, wind speed, and sunshine duration, to understand their interactions across different seasons and climate zones. Additionally, we will analyze soil temperature variations in different regions to assess the effect of latitude and conduct experiments to observe whether covering soil with fallen leaves or plastic sheets alters its temperature.

III. Literature Review

1.Soil Temperature and Crop Growth

Soil temperature regulates microbial activity, affecting the decomposition rate of organic matter and seed germination. Additionally, it influences the efficiency of water and nutrient absorption by plant roots. As temperature increases, root water absorption efficiency improves until reaching the upper limit of the plant's growth range. Moreover, soil temperature impacts soil moisture, structure, and freezing phenomena, which indirectly affect plant growth. The following figure illustrates the relationship between soil temperature and corn yield:



Chart[1]

Chart[1]The dry yield of young corn is affected by the average soil temperature at 10 cm depth below the surface.(From Altering soil temperature for optimum plant growth *Lo, Kwong Fai Andrew*)

From the graph, it is evident that at 27°C, the highest dry corn yield is achieved. Any deviation above or below this temperature results in reduced yield, demonstrating the impact of temperature on crop growth.

2.Controlling Soil Temperature

Several factors influence soil temperature:

(1)Solar radiation (soil absorbs 80% of solar radiation)

(2)Soil properties (thermal conductivity, particle size, moisture content)

(3)Soil management (e.g., farming practices affecting soil properties)

(4)Soil water content

Measures to regulate soil temperature include:

(1)Reducing excessive soil temperature: Mulching with organic material to lower temperature and increase moisture content.

(2)Increasing low soil temperature: Covering with transparent plastic to trap water vapor and use the greenhouse effect to raise temperature; covering with dark plastic to absorb solar radiation and prevent heat loss.

(3)Maintaining optimal soil moisture levels: Water has a high specific heat capacity, which helps stabilize temperature fluctuations.

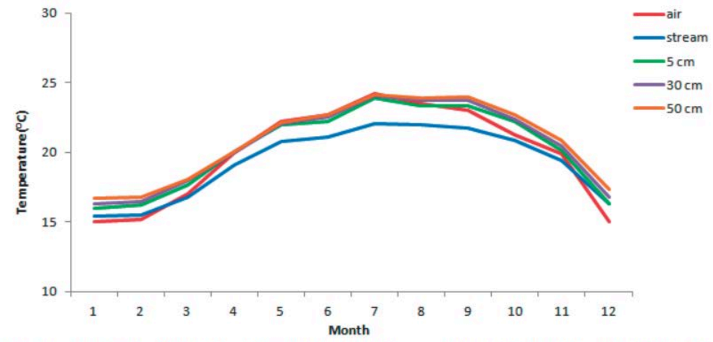
(4)Deepening the effective soil layer: Soil temperature becomes more stable at greater depths. The "effective soil layer" provides space for root growth. Compacted soil layers limit root penetration, making crops more vulnerable to temperature fluctuations. Mechanical tools can break compacted layers to deepen the effective soil layer.

3.Relationship Between Surface Soil Temperature and Air Temperature

Since atmospheric heat, surface soil, and low-flow rivers primarily receive energy from solar radiation, they exhibit a high correlation. During the daytime (9 AM to 5 PM), air temperature is usually higher than surface soil temperature, while at night, soil temperature tends to be higher. A regression analysis of surface soil temperature at a 5 cm depth (Ts05) and air temperature (Tair) at Lianhuachi No.3 experimental watershed produced the following equation:

Ts05 = -0.659 * Tair + 33.406

This analysis revealed a positive correlation exceeding 90%.

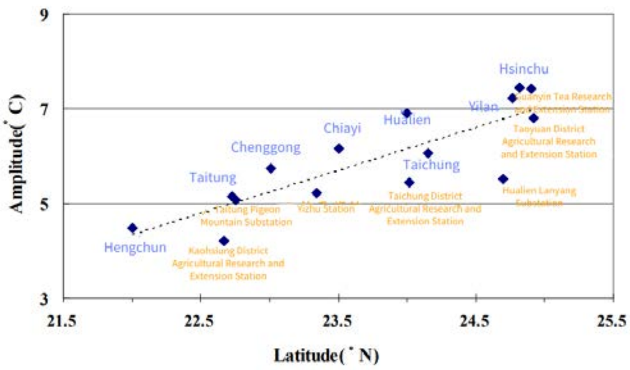


Chart[2]

Chart[2]Monthly Average Temperatures of the Atmosphere, Stream Water, and Surface Soil in the Wetland of Lianhua Pond No.3(From Study on the relationship between the air, stream and surface soil temperature in the waterfront area of Lianhuachi No.3 catchment area)

4.Relationship Between Surface Soil Temperature and Latitude

Soil surface temperature amplitude generally increases with latitude. In Taiwan, for example, the southernmost Hengchun station records an amplitude of 4.49°C, while the northernmost Taoyuan Agricultural Research Station records 6.81°C. Higher latitudes experience greater annual climate variation, while areas closer to the equator exhibit smaller seasonal fluctuations. Despite Taiwan's small north-south distance, the influence of mid-latitude weather systems varies, with northern regions experiencing greater impacts, leading to higher soil temperature fluctuations compared to southern regions.



Chart[3]

Chart[3] The variation in surface soil temperature amplitude at each monitoring station according to latitude is shown in the figure. The figure includes the results of monitoring stations from the Central Weather Bureau (Wu and Hsu, 2003). The dashed line represents the linear regression of soil temperature amplitude for all monitoring stations.

Further comparisons between Guanyin Tea Research Station and Taoyuan Agricultural Research Station (with similar latitudes and climates) show that the former has a lower soil thermal diffusivity, resulting in greater temperature fluctuations. This may be due to soil type differences: Guanyin contains more clay, whereas Taoyuan primarily consists of silty clay. Additionally, Guanyin's higher elevation reduces groundwater influence, while Taoyuan's lower elevation leads to greater groundwater effects. Similarly, the thermal diffusivity of Taitung Banjou Research Station exceeds that of Kaohsiung Agricultural Research Station, likely due to variations in soil type, terrain, and stone content. Stones conduct heat better than soil, affecting thermal diffusivity. Overall, soil thermal diffusivity is influenced by soil type, moisture content, depth, and environmental conditions.

(Note: A higher soil thermal diffusivity means soil transfers heat more efficiently to deeper layers during the day and releases heat more effectively at night, resulting in smaller temperature fluctuations.)

5.Soil Temperature Variations at Different Depths

Daily temperature fluctuations are most pronounced in surface soil. At 30 cm depth, daily temperature variation is usually less than 3°C; at 60 cm depth, variation is typically below 1°C; and at 100 cm depth, daily temperature differences are nearly zero.

When vegetation covers the soil or soil moisture is high, daily soil temperature variations become less noticeable. Before sunrise, soil temperature is lowest at the surface and increases with depth. The highest surface soil temperature occurs around the same time as the highest air temperature, while deeper layers experience delayed temperature peaks and troughs. This lag time depends on surface conditions, soil type, and moisture content. Water has a high specific heat capacity (1.00 cal/g) compared to soil minerals (~0.2 cal/g), meaning increased soil moisture enhances thermal conductivity and heat diffusion, significantly influencing soil temperature.

IV.Research Methodology and Overview of Research Questions

We will analyze the data between soil temperature and various meteorological factors, studying the trends of soil temperature changes over different years and the differences in soil temperature across regions with different latitudes. At the same time, we will conduct a literature review and empirical research to explore the following questions:

(1)The relationship between soil temperature and air temperature

(2)The relationship between soil temperature and humidity

(3)The relationship between soil temperature and cloud cover

(4)The relationship between soil temperature and wind direction/speed

(5)The variation of soil temperature across different years

(6)The impact of latitude on soil temperature

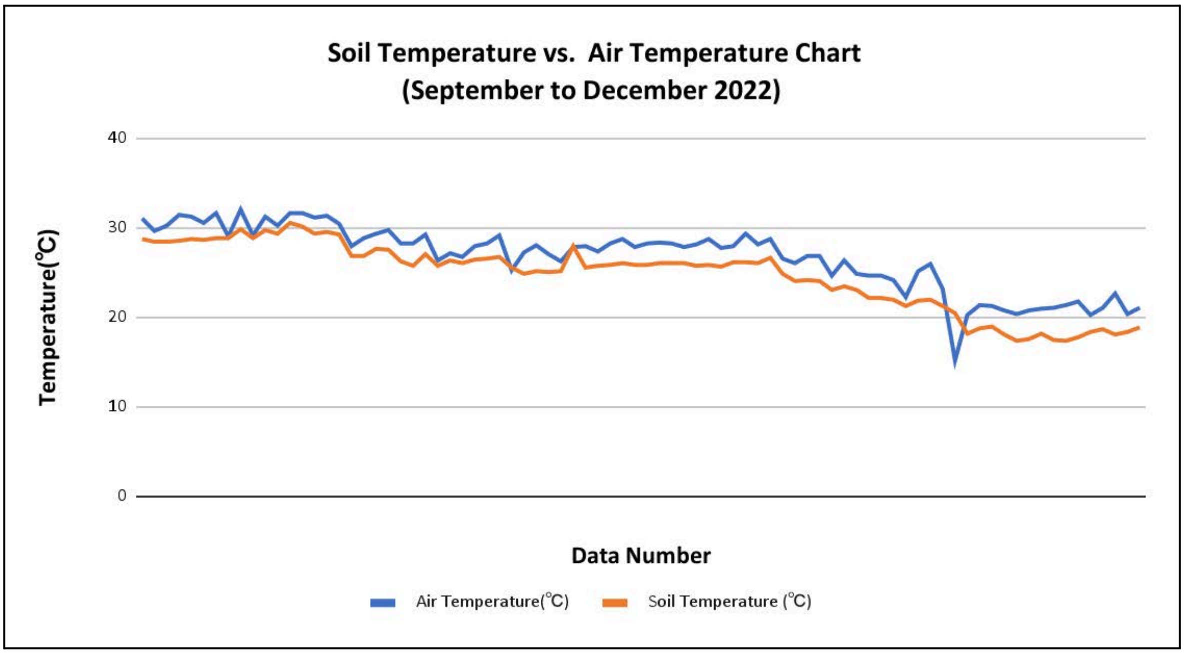
(7)The effect of soil temperature on plant growth

V. Data Analysis

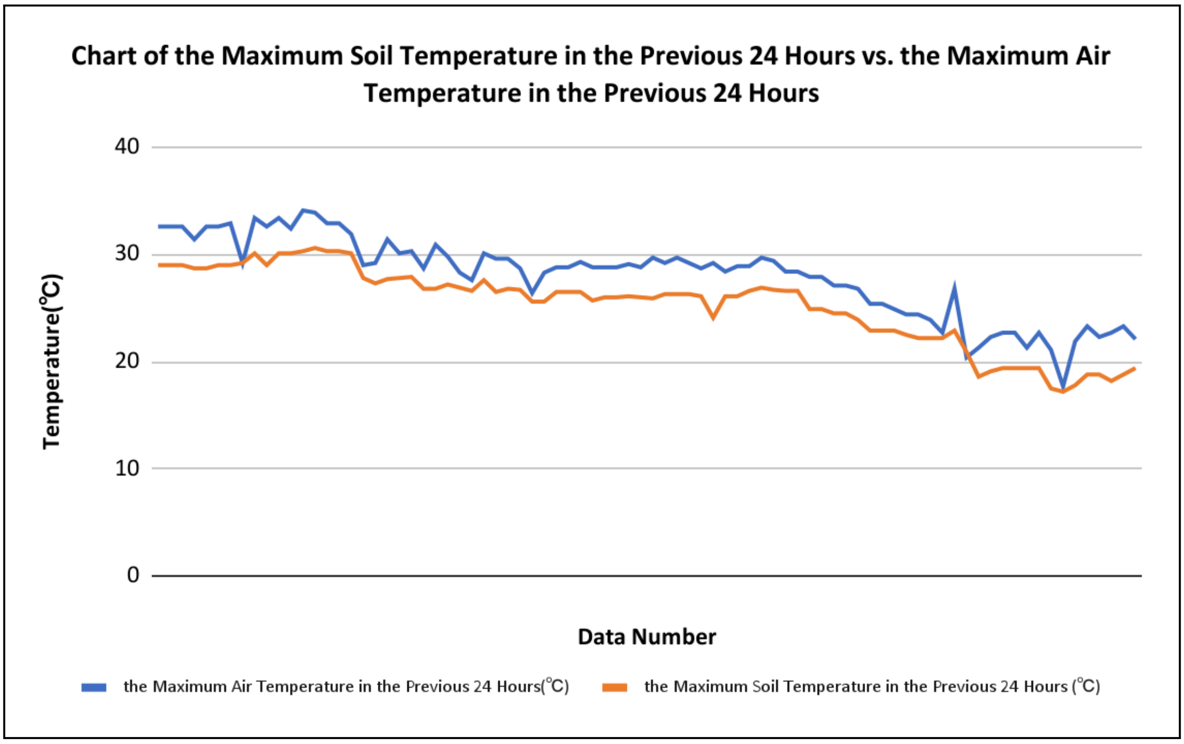
1. Relationship between Soil Temperature and Different Meteorological Factors

(1) Relationship between Soil Temperature and Air Temperature

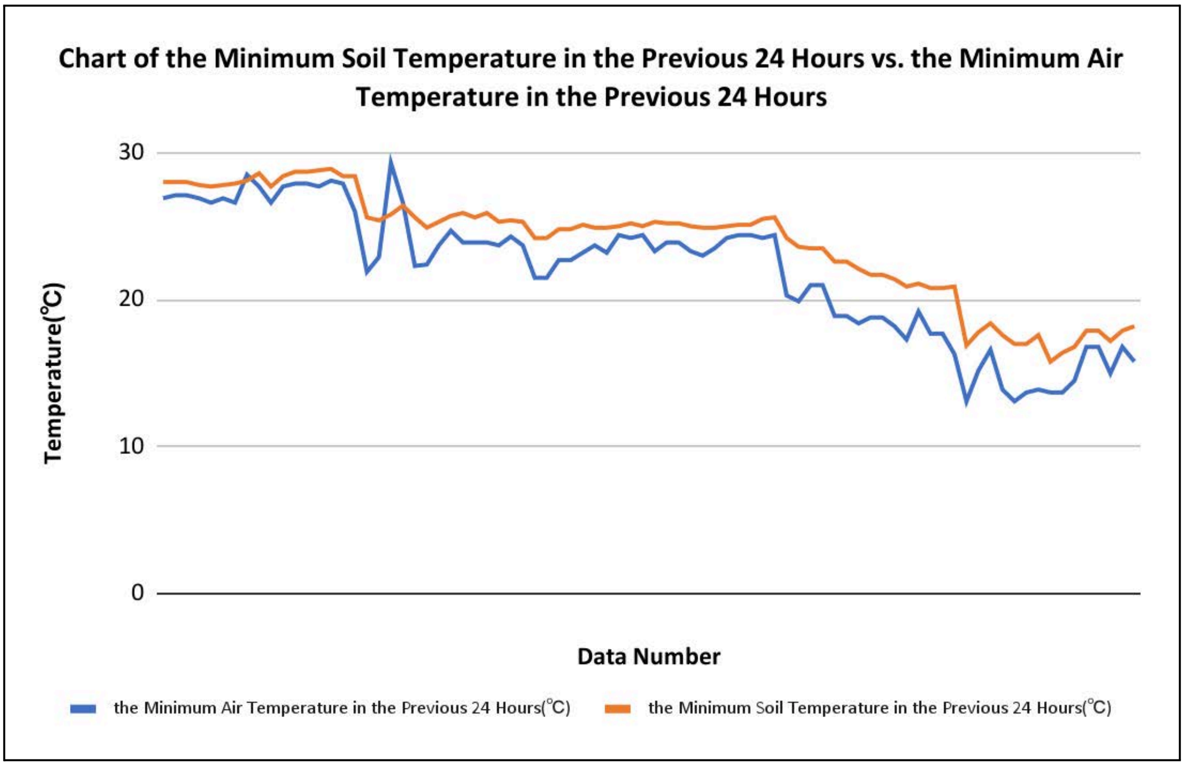
Chart[4] to Chart[6] were created by ourselves (Data observation location: Kaohsiung Municipal Kaohsiung Girls' Senior High School,Taiwan, Data observation period: September to December 2022).



Chart[4]



Chart[5]

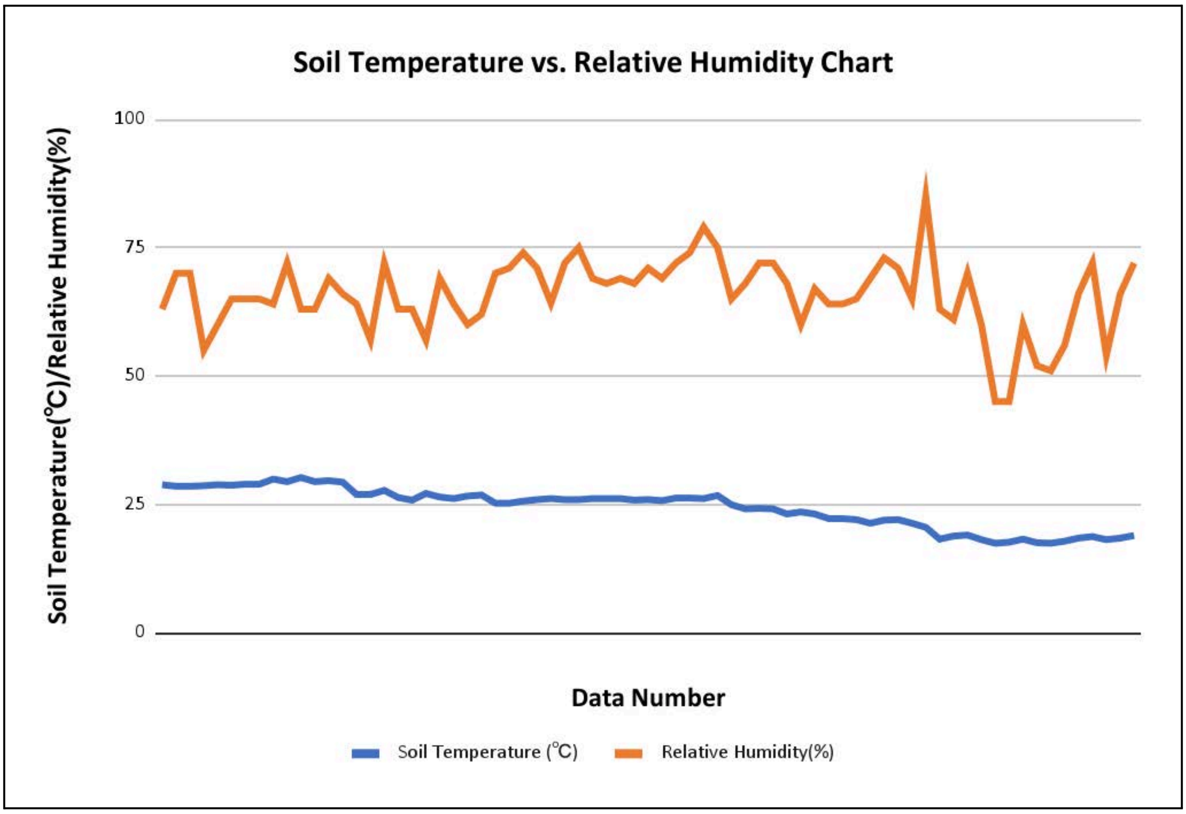


Chart[6]

We observed that the air temperature and soil temperature generally follow similar trends, with soil temperature being more stable than air temperature. Except for a few observations where there were slight discrepancies between the two (which might have been influenced by other meteorological factors), we infer that there is a positive correlation between soil temperature and air temperature. When the air temperature rises, the soil temperature also increases, but usually stays lower than the air temperature; conversely, when the air temperature drops, the soil temperature also decreases, but at a slower rate.

(2) Relationship between Soil Temperature and Relative Humidity

Chart[7] was created by ourselves (Data observation location: Kaohsiung Municipal Kaohsiung Girls' Senior High School,Taiwan, Data observation period: September to December 2022) (Some data was deleted due to the absence of recorded relative humidity).



Chart[7]

Observations:

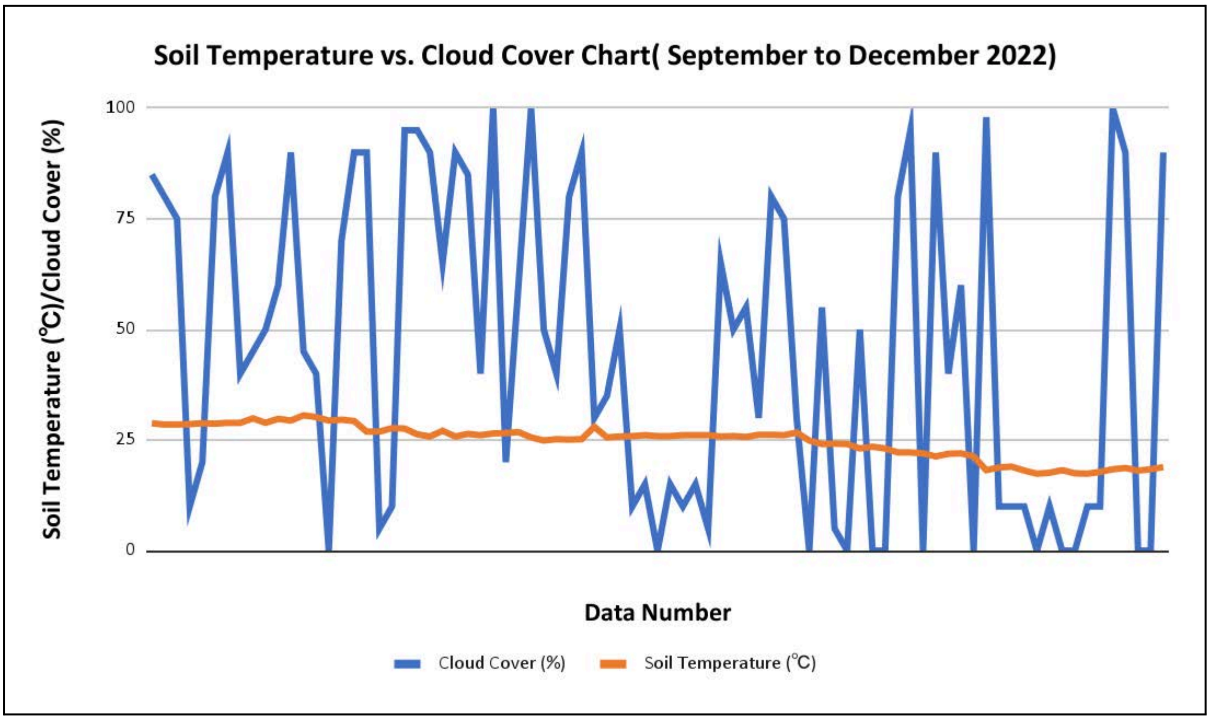
■ Soil Temperature (Blue line): Initially, the soil temperature was around 30°C, and over time, it gradually decreased to about 20°C. The trend was relatively smooth, with no significant fluctuations.

■ Relative Humidity (Orange line): The relative humidity ranged from about 60% to 85%, with more noticeable fluctuations. In some data points, the relative humidity was either higher or lower, possibly influenced by weather, rainfall, or other factors.

Conclusion: We infer that there is a negative correlation between soil temperature and relative humidity. As the soil temperature decreases, relative humidity gradually increases. This might be related to the rate of water evaporation: when the soil temperature is higher, water evaporates more quickly, resulting in lower relative humidity; when the soil temperature is lower, water evaporation decreases, causing the relative humidity to rise.

(3) Relationship between Soil Temperature and Cloud Cover/Cloud Types

Chart[8] and Table[1] were created by ourselves (Data observation location: Kaohsiung Municipal Kaohsiung Girls' Senior High School,Taiwan, Data observation period: September to December 2022) (Some data was deleted due to the absence of recorded cloud cover or cloud type).



Chart[8]

Observations:

■ Soil Temperature (Orange line): The overall change in soil temperature is relatively stable, remaining between 25°C and 30°C. Although there are slight fluctuations, the overall trend is not significantly affected.

■ Cloud Cover (Blue line): There is no clear negative correlation between high cloud cover and soil temperature.

Cloud Types	Average Soil Temperature (°C)
No Clouds	21.73
Cumulonimbus	24.33
Cumulus	26.31
Stratocumulus	26.36
Stratus	23.23
Cirrostratus	24.33
Cirrus	26.33
Cirrocumulus	22.40
Altostratus	22.08
Altocumulus	22.20

Table[1]

Observations:

■ Cumulus (26.31°C), Stratocumulus (26.36°C): In environments with cumulus or stratocumulus clouds, the average soil temperature was higher. This may be due to the relatively low coverage of these clouds, allowing sunlight to penetrate and warm the surface, resulting in higher soil temperatures.

■ Cumulonimbus (24.33°C), Nimbostratus (24.33°C): In environments with cumulonimbus or nimbostratus clouds, the average soil temperature was lower. This could be because these clouds are typically associated with precipitation, which affects the absorption of surface heat and further lowers the soil temperature.

■ Stratus (23.23°C), Cirrocumulus (26.33°C), Cirrostratus (22.40°C), Cirrus (22.08°C), Cirrocumulus (22.20°C): In environments with high-level clouds like cirrostratus, cirrus, or cirrocumulus, the average soil temperature was lower. This is likely because these clouds are higher up, and their influence on the surface is minimal.

■ No Clouds (21.73°C): In cloudless conditions, the average soil temperature was the lowest (21.73°C), likely due to the faster heat loss from the surface, resulting in lower soil temperatures.

Conclusion:

■ Overall, short-term variations in cloud cover did not cause significant changes in soil temperature, but there could be long-term effects that would require prolonged observation to fully understand.

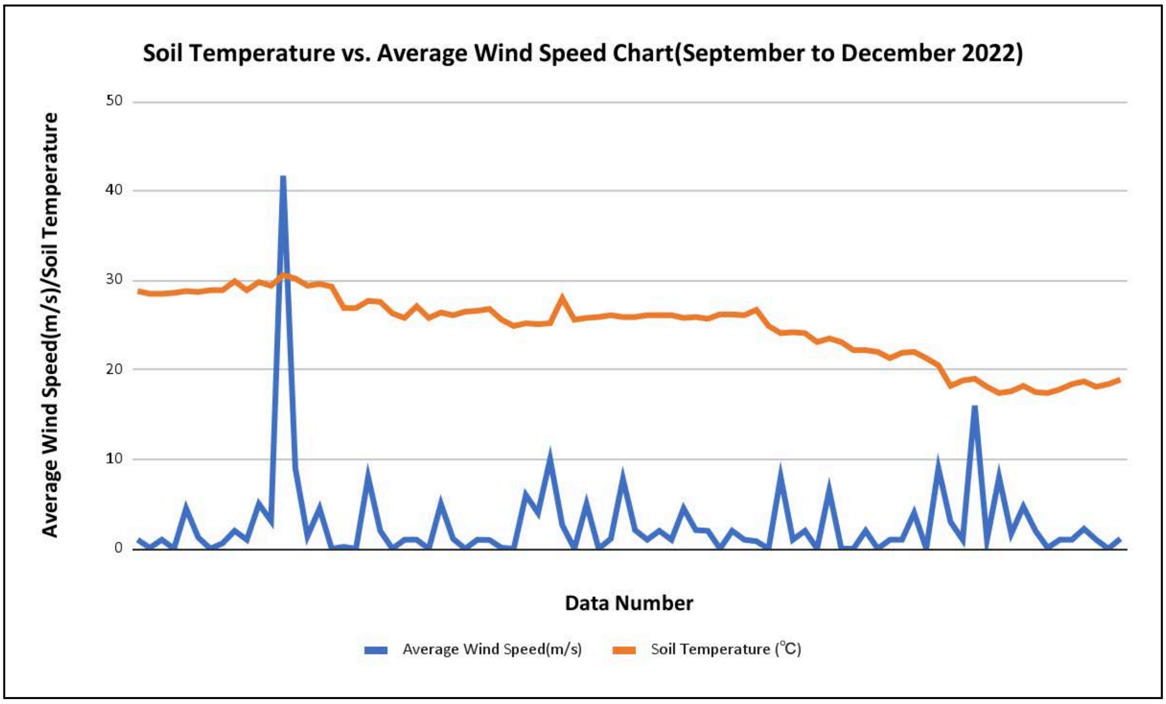
■ In environments with cumulus or stratocumulus clouds, the average soil temperature is higher. This may be because these clouds are thinner, allowing more sunlight to warm the surface, thus raising the soil temperature.

■ In environments with nimbostratus or cumulonimbus clouds, the average soil temperature is lower. This is likely due to the precipitation associated with these clouds, which brings cooler air and lowers the soil temperature.

■ In cloudless environments, the average soil temperature is the lowest, indicating that the heat dissipation effect is stronger without cloud cover.

(4) Relationship between Soil Temperature and Wind Direction/Speed

Chart[9] and Table[2] were created by ourselves (Data observation location: Kaohsiung Municipal Kaohsiung Girls' Senior High School,Taiwan, Data observation period: September to December 2022)



Chart[9]

Observations:

■ Soil Temperature (Orange line): The soil temperature remains relatively stable, staying between about 25°C and 30°C. There is a slight decrease after the 70th data point, which could be related to seasonal changes or an increase in wind speed.

■ Wind Speed (Blue line): The wind speed shows larger fluctuations, but for most of the time, it remains low. A peak wind speed is observed at the 13th data point (close to 40 m/s), likely due to a short-lived strong wind event, which may have a short-term impact on soil temperature. The wind speed exhibits occasional small fluctuations, but overall, the trend is low, and there is no significant correlation with soil temperature changes, indicating that wind may have a temporary effect on soil temperature.

Wind Direction	Average Soil Temperature (°C)
Northeast (including true North)	26.38
Southeast (including true South)	22.64
Southwest	24.37
Northwest	24.37

Table[2]

Observations:

■ Northeast (including true North): Average soil temperature of 26.38°C, the highest among the directions, which may be due to favorable sunlight conditions during the observation or minimal influence from the wind at this observation point.

■ Southeast (including true South): Average soil temperature of 22.64°C, the lowest, suggesting that wind from the southeast may bring cooler air, resulting in lower soil temperatures.

■ Southwest: Average soil temperature of 24.37°C, moderate, slightly higher than the southeast.

■ Northwest: Average soil temperature of 24.37°C, similar to the southwest, indicating that the wind impact from the northwest is similar to that of the southwest wind.

Conclusion:

■ The change in soil temperature is relatively stable and not easily affected by wind speed, although brief, strong wind events may cause small fluctuations.

■ Short-term strong wind events may impact soil temperature, but long-term variations in wind speed do not significantly alter soil temperature.

■ Strong winds from specific directions (such as the southeast) may have a more noticeable effect on soil temperature.

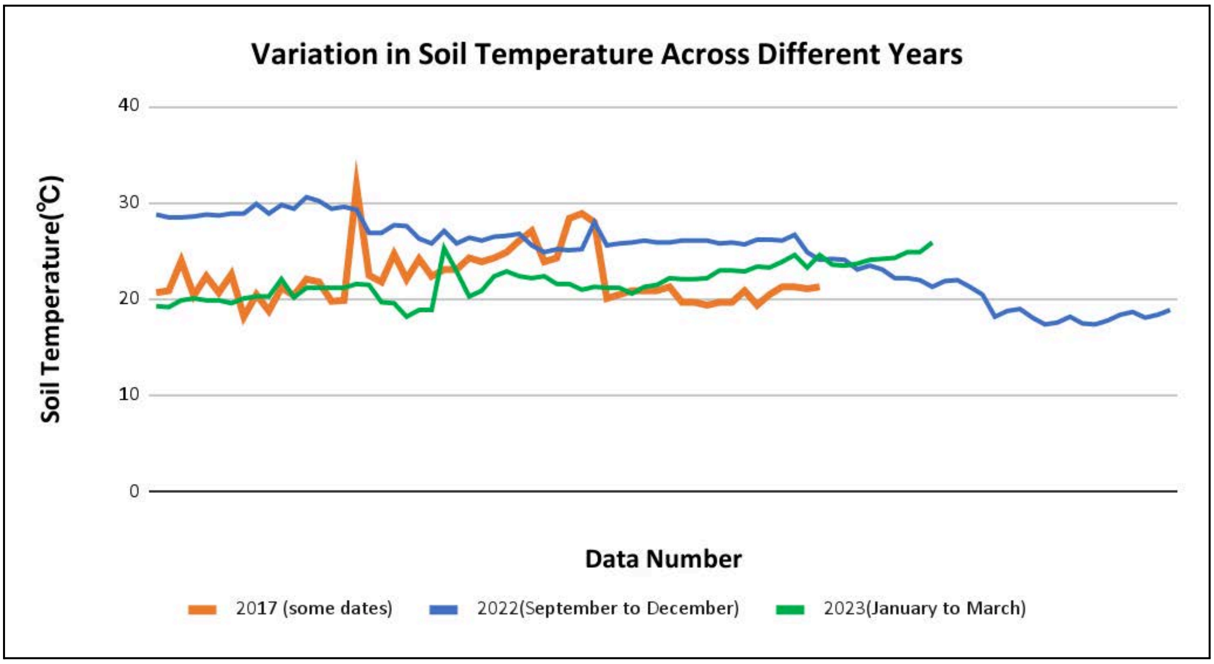
■ Wind direction can influence soil temperature variations, particularly winds from the southeast, which may lower soil temperature.

■ Winds from the northeast (including true North) may be warmer, leading to higher soil temperatures.

■ The effects of wind from the northeast (including true North) and southeast (including true South) on soil temperature are more significant compared to winds from the southwest and northwest, which could be related to the location of the observation site (windward or leeward).

2. Variation in Soil Temperature Across Different Years

Chart[10] was created by ourselves (Data observation location: Kaohsiung Municipal Kaohsiung Girls' Senior High School,Taiwan, Data observation periods: 2017 (some dates), 2022 (September to December), 2023 (January to March)).



Chart[10]

(1) Observations:

■ 2017 (Orange line): The soil temperature shows more fluctuations, with the overall range between 15°C and 30°C, indicating greater variability. The largest variations are likely due to the data being collected over a more spread-out time period (covering both spring/summer and autumn/winter), where seasonal environmental changes could have contributed to larger temperature shifts.

■ 2022 (September to December) (Blue line): The soil temperature remained relatively stable, staying around 25°C for most of the period. Toward the end, there was a downward trend in temperature, which may be due to the onset of winter, leading to a gradual decrease in soil temperature.

■ 2023 (Green line): The soil temperature remained relatively stable, mostly around 20°C, with a smaller range of variation compared to 2017. The trend in early 2023 was quite steady, with little change compared to the second half of 2022, indicating a more stable soil environment.

(2) We hypothesize the causes for these observations:

■ Seasonal Changes: The data for 2022 was collected from September to December, while the data for 2023 spans from January to March. Therefore, the differences in temperature could be influenced by seasonal changes.

■ Soil Moisture and Covering Materials: These are factors that can affect the stability of soil temperature and may contribute to the differences observed between years.

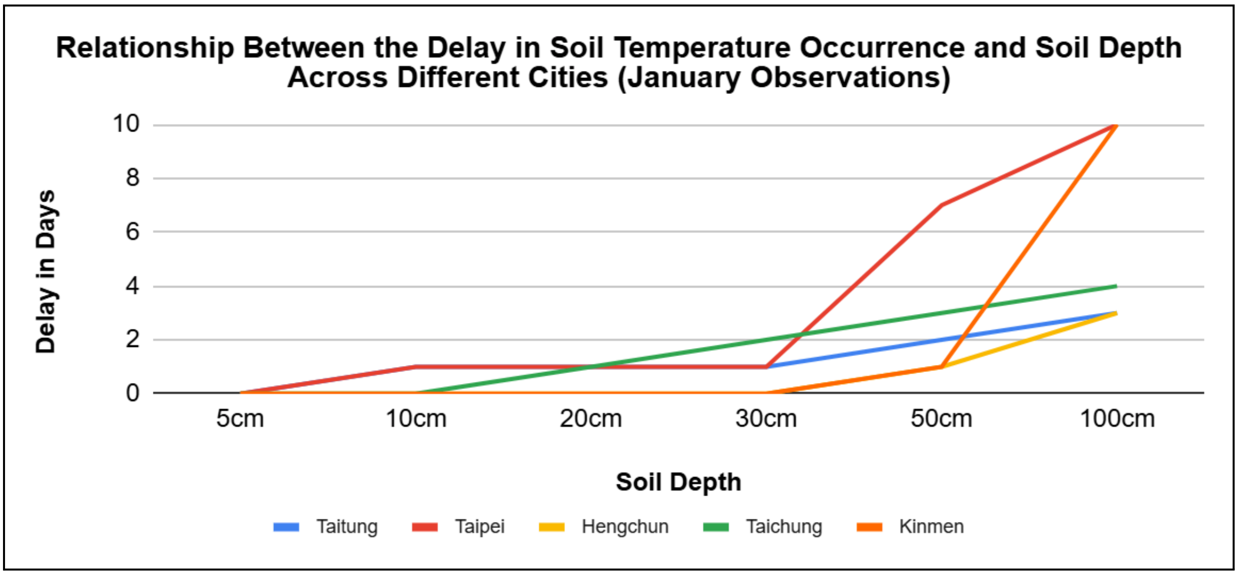
(3) Conclusion:

In 2017, soil temperature exhibited greater fluctuations, while in 2022 and 2023, the temperatures were relatively stable, with 2023 showing the most consistent soil temperature, particularly in the early part of the year. This could be due to factors such as climate conditions, rainfall, surface cover, and seasonal variations at the time.

3. Soil Temperature and Delay Differences at Different Latitudes

(1) Investigating Whether There Is a Delay in the Time When the Soil Temperature Reaches Its Minimum at Different Depths Across Different Counties

Chart[11] was created by ourselves (Data source: Central Weather Bureau, Data observation period: January 2025).



Chart[11]

(Note: Soil temperature delay calculation method: Delay time = the date the deep soil temperature reaches its lowest point - the date the surface soil temperature reaches its lowest point).

(1) Observations:

■ Overall Trend: In all counties, there is a delay in soil temperature. The deep soil temperatures in all regions reached their lowest point later than the surface soil temperatures. This is likely because the shallow soil is more affected by external air temperatures, and possibly because the surface soil has lower moisture content and specific heat, which leads to faster temperature change.

■ Analysis of Minimum Soil Temperature in Various Counties: In general, the minimum soil temperatures across different counties occurred between January 12 and 17, showing that soil temperature changes were similarly influenced by similar climatic factors. Upon verification, it was confirmed that a strong cold air mass passed through during that week, causing a simultaneous drop in soil temperatures.

■ Hengchun, Taitung, and Taichung: These regions show similar soil temperature changes, and the overall delay time is relatively short. The minimum temperatures at depths of 10cm, 20cm, and 30cm were delayed by only one day, while those at depths of 50cm and 100cm were delayed by 1 to 4 days. This is likely due to the stable and warm climate in these areas, with smaller day-night temperature variations, which results in minimal differences between surface and deep soil temperatures. Additionally, these areas tend to have drier soils, which enhances thermal conductivity. Therefore, the temperature changes in Hengchun, Taitung, and Taichung are similar, with a shorter delay compared to Taipei and Kinmen.

■ Taipei and Kinmen: The delay in deep soil temperatures in these areas is significantly longer than in other counties (in Taipei and Kinmen, the 100cm layer had a 10-day delay, while Taichung’s 100cm layer had only a 4-day delay, and Taitung and Hengchun’s 100cm layers had a 3-day delay). The first reason for this could be the influence of the Northeast Monsoon during winter, which causes more dramatic temperature changes and makes the soil slower to cool, requiring more time to adapt to environmental changes (since the thermal capacity of soil is much greater than that of air). As a result, the delay in soil temperature changes is greater in these areas. In contrast, other regions (Taichung, Taitung, Hengchun) have more stable climates and smaller temperature variations, allowing soil temperatures to change more quickly and with shorter delays. The second reason could be that Taipei and Kinmen receive more precipitation due to the Northeast Monsoon, which increases soil moisture content and, consequently, the soil's heat capacity, leading to delayed cooling. On the other hand, Taichung, Taitung, and Hengchun are drier, which results in lower heat capacity and faster cooling at deeper soil layers (3–4 days). In summary, the climate, soil moisture content, and geographical environment are strongly related to temperature delays.

■ For Taipei: Although the shallow soil layers (10cm–30cm) did not show significant delays (only a one-day delay), the delay was still larger than in other regions, likely for the reasons mentioned in point (4) for deep soil. Furthermore, the delay at the 50cm depth in Taipei was 7 days, which is significantly larger than the delay in the shallow layers, which could be attributed to differences in soil properties or moisture content, causing slower heat conduction at greater depths. Finally, compared to the 50cm layer, the 100cm layer only had a 10-day delay, which is a smaller delay than expected (since temperature changes should generally be more delayed at greater depths). This discrepancy could be due to differences in soil density and moisture content at different depths, affecting the speed of heat diffusion.

VI. Discussion of Research Results

Experiment Title: The Effect of Different Soil Temperatures on Plant (Mung Bean) Growth
Experiment Dates: February 3 to February 7, 2025

1. Purpose of the Experiment

The purpose of this experiment is to understand the effect of soil temperature on the growth of plants (mung beans).

2. Principle of the Experiment

(1)Using Plastic Wrap: The principle of the greenhouse effect is used to increase the soil temperature.

(2)Using Fallen Leaves: The fallen leaves cover the soil to reduce its temperature and increase soil moisture.

3. Materials

- Soil
- Mung beans
- Glass thermometer
- Plastic wrap
- Fallen leaves
- Water
- Jars (three jars)

4. Experiment Procedure

(1)Take three jars and add appropriate amounts of soil and mung beans to each.

(2)After planting the mung beans, cover one jar with plastic wrap, another with fallen leaves, and leave the last one uncovered as the control group.

(3)Water the plants regularly and use a glass thermometer to measure the soil temperature in each jar.

(4)Observe and record the growth of the mung beans regularly.

5. Experimental Results

(1)Soil Temperature Record (°C):(Table[3] was created by ourselves).

Date	No Cover	Plastic Wrap	Fallen Leaves
2/3	18	18	18
2/4	20	21	19
2/5	19	20	19
2/6	21	22	20
2/7	19	21	18

Table[3]

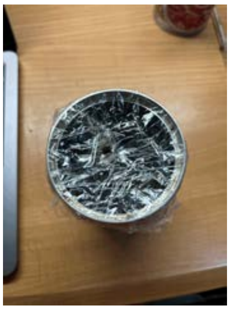
(2)Mung Bean Growth Conditions:(All pictures were taken by ourselves).

■ No Cover: The mung beans grew well, reaching about 9 cm, indicating that the soil without any cover provided better conditions for growth.

Picture[1]

Picture[2]

■ Plastic Wrap: Only one small sprout appeared, suggesting that high temperatures may have inhibited germination and growth.

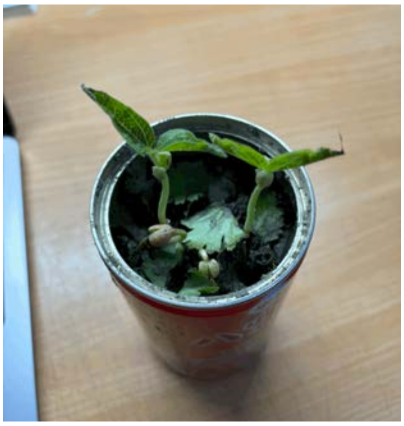


Picture[3]

Picture[4]

■ Fallen Leaves: The mung beans grew slower, reaching about 5 cm. The fallen leaves helped to maintain soil moisture, but the growth was weaker compared to the no-cover group.





Picture[5] Picture[6] Picture[7]

6. Discussion and Analysis

(1)Effect of Soil Temperature:

From the experimental results, it is observed that the soil temperature under the plastic wrap was higher (reaching a maximum of 22°C), while the soil temperature with fallen leaves was lower (minimum of 18°C). The soil temperature without any cover fluctuated, but still provided conditions suitable for mung bean growth.

(2)Mung Bean Growth:

■ No Cover: The soil temperature in this group fluctuated moderately, and without the constraints of plastic wrap or fallen leaves, the mung beans germinated and grew quickly, reaching about 9 cm.

■ Plastic Wrap Covered Soil: The high temperature created an unsuitable environment for growth. The mung beans germinated slowly, with only one small sprout, possibly because the high soil temperature inhibited root development, thus restricting growth.

■ Fallen Leaves Covered Soil: The average soil temperature was relatively low in this group, which hindered mung bean growth, with the plants reaching only about 5 cm.

7. Conclusion

The experiment results show that soil temperature significantly affects the growth of mung beans. The soil without any cover provided the best growth conditions, while excessively high soil temperatures (as in the case with plastic wrap) inhibited germination and growth. Fallen leaves helped to maintain soil moisture and slightly lower the temperature, but the mung beans still grew weaker compared to the control group. This experiment highlights the importance of soil temperature in plant development.

VII. Conclusion

Through data analysis, it is evident that air temperature and soil temperature are closely related, while other meteorological factors primarily influence soil temperature changes under extreme conditions. When looking at soil temperature variations across different years, the primary cause of these changes is the climate of the year, which can be traced back to the influence of various meteorological factors.

In terms of latitude, regions that are geographically closer tend to exhibit similar soil temperature changes. However, since the selected areas in this study do not have significant latitude differences, their overall soil temperature trends are similar. The notable difference is observed in higher-latitude areas, where the winter northeast monsoon has a more pronounced impact. This leads to a rise in both air temperature and soil moisture, causing the deeper soil layers to reach their lowest temperature later than in lower-latitude areas. This phenomenon is closely tied to the region's climate and soil characteristics.

From the experimental results, it is clear that soil temperature has a significant effect on plant growth. Both excessively high and low soil temperatures are detrimental to plant growth. Therefore, through this experiment, we can potentially improve agricultural conditions by manipulating soil temperature, thereby creating a better growing environment for plants and addressing challenges in agriculture.

VIII. References

Altering soil temperature for optimum plant growth *Lo, Kwong Fai Andrew*
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Soil Temperature Overview
https://ws.tfri.gov.tw/001/Upload/OldFile/files/%E5%B0%88%E8%A8%8A_152-2-5.pdf

Chen Xingzong/For crops to grow well, it is very important to control the soil temperature of farmland. Let's take a look at the five major soil temperature management strategies!
https://www.newsmarket.com.tw/blog/174020/