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INFLUENCE OF SOIL TEMPERATURE ON ROOT DEVELOPMENT AND MICROBIAL DIVERSITY IN PADDY FIELDS: A COMPREHENSIVE REVIEW

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Background: The expected global climate change, in addition to increasing air temperature and CO_2 levels, will manifest itself in changes in precipitation and various physical, chemical and biological soil indicators that are responsible for its fertility and productivity. Potential impact of global warming on soil fertility will primarily manifest itself in changes in soil hydrology and temperature. Changes in soil temperature and physicochemical properties due to climate warming ultimately affect crops. **Objectives:** The current review aims to systematize some of the key advances in the relationship between soil temperature, root development and microbial communities. It is hoped that organizing the results achieved to date will allow other researchers to better understand the existing gaps and continue to advance this field of knowledge to address climate change and its impacts. Because the right choice of future research should contribute to achieving SDG 2 "Zero Hunger" by 2030. **Methods:** When writing the review, analysis and synthesis were used, mainly of recent scientific publications in the studied field of knowledge, as well as induction and deduction of the information obtained. There were no research restrictions on the type of publication, the country of the authors, the language, or the number of citations. For the review, mainly recent sources no older than 10 years were selected. **Results:** Microorganisms respond within their limitations when exposed to temperature variations. Different microbial species may have very different soil temperature preferences; and slow temperature variations favour the selection of the fittest species, allowing the microbial community to adapt. The most significant environmental factor affecting the development and activity of microorganisms in soil is temperature in combination with water content. Soil respiration refers to the transfer of CO_2 from soil to air, primarily by soil microorganisms and plant roots. The rate of soil respiration decreases exponentially with increasing latitude and increases with increasing temperature. Several field and laboratory studies have shown a positive correlation between soil respiration and temperature. Rising global temperatures are expected to increase the respiration rate of bacteria that break down organic carbon in soils, resulting in a 40% increase in CO_2 emissions. **Conclusion:** In the future, plant and microbial activity variations will be closely related to changes in soil temperature and moisture, and these micro-ecological interactions will be critical in nutrient availability and net ecosystem productivity. Microbes determined to be beneficial are an essential component in maintaining soil quality and paddy production. Despite increasing temperature stress tolerance, heat and cold shocks continue to limit rice output. The physiology of temperature-sensitive root mechanisms in rice and the interaction between shoot and root growth should be better understood to better understand. Because the effects of soil chemical and microbial activity were included in the soil temperature treatments in this study, it was necessary to separate these indirect effects from the direct sensitivity of the root growth process to changes in soil temperature.

Keywords: soil temperature; root growth; microbial diversity; paddy.

INTRODUCTION

Researchers and experts have identified a possible increase in ambient temperature as a result of global warming of more than 1 °C above pre-industrial levels from 2030 to 2052 if it is not stopped then this rate is not expected to change (Vanisree et al., 2022). The expected global climate change, in addition to increasing air temperature and carbon dioxide (CO_2) levels, will manifest itself in the form of changes in precipitation and various physical, chemical and biological properties of the soil that are responsible for its fertility and productivity. The potential impact of climate change on soil health will primarily manifest itself in changes in soil temperature regime and soil hydrology. Ultimately, vegetation is sensitive to temperature changes due to global warming and, as a consequence, to changes in the physicochemical properties of the soil.

In recent years, some studies have already found that the increase in temperature accelerated the evapotranspiration from the rice field and increased the crop water requirement; as a result, the vegetative stage of rice was shortened, which caused a decrease in yield; due to the mutual movement of metabolites between above-ground and below-ground organs, an adverse effects on plant root growth was found due to the rising soil temperature at the late growth stage (Chakraborty et al., 2022). Such observations are also supported by earlier studies by Yoshida (1973).

Considering the active industrialization, intense soil pollution and accumulation of toxic elements in fertile lands, the combined effects of soil temperature and cadmium on soil microbial activity were investigated. It was found that the combined effects reduced microbial colonization and nitrogen uptake from soil, and had detrimental effects on plant growth hormones and ultrastructure (Munir et al., 2023).

Increased induction of abiotic stresses to food plants due to global climate change contributes to reduced growth and yields, and as a result, reduces global agricultural production, especially rice production (Saud et al., 2022).

Sustainable Development Goal (SDG) 2 – Zero Hunger – is projected to be missed by 2030. This was reported in the latest State of Food Security and Nutrition in the World report. The report says the world has been set back 15 years, with undernourishment levels back to 2008 – 2009 levels (FAO, 2024). The report also finds that food insecurity and malnutrition are being exacerbated by a range of factors, including the impacts of climate change.

Therefore, the objective of this review is to systematize some of the key advances in the relationship between soil temperature, root development and microbial communities. It is expected that systematization the results achieved to date will allow other researchers to better understand the existing gaps and further advance this area of knowledge to address climate change and its impacts. Because the right choice of future research should contribute to achieving SDG 2 "Zero Hunger" by 2030.

When writing the review, analysis and synthesis were used, mainly of recent scientific publications in the studied field of knowledge, as well as induction and deduction of the information obtained. There were no research restrictions on the type of publication, the country of the authors, the language, or the number of citations. For the review, mainly recent sources no older than 10 years were selected, with some exceptions, if this was required within the framework of the study, for example, to compare results over time.

FACTORS INFLUENCING SOIL TEMPERATURE

Rice (Oryza Sativa L.) is one of the most significant grain crops for more than 50% of the world's population, accounting for about 20% of the total energy intake. An annual increase of 8 – 10 million tonnes is projected to be needed to fulfil potential needs (de Almeida Fernandes et al., 2018). Asian rice (Oryza Sativa L.) is one of the world's most significant and most commonly produced cereals, second only to wheat in its annual contribution to food intake (Shamshiri et al., 2018). Considering that only 7% of the world's total rice production is marketed, local rice production must be increased to create rice self-sufficiency in the country (Rajamoorthy & Munusamy, 2015). The instability of supply, the demand increasing, and trading quantities of rice in a small international market result in rice prices fluctuating (Vaghefi et al., 2016). Accordingly, efforts will be focused on strengthening the paddy and rice country industry by increasing the productivity and quality of paddy yield. Among the main factors influencing the increased paddy yield are soil fertility and nutrient requirements for plants. Soils have a series and a fertility class different. There are three types of soil for most soils rice fields in Malaysia, namely sea lanar, river lanar and organic different parent material content, physical and chemical properties which affects her fertility levels. Fertile soil can supply beneficial nutrients at appropriate rates and increase the ability of plants to absorb nutrients to obtain high rice yields. In terms of temperature, rice is suitable to be grown at the optimum temperature around 20 – 33 °C. Areas that are too hot and dry will cause a decreasing in paddy yield. The environment's temperature affects plant growth and development, and each species has different optimum temperatures for growth, development, and reproduction (Hasanuzzaman et al., 2019). Soil temperature is a broad concept because it can be used to classify heat properties. Temperature is more certainly a significant determinant of microbial population composition (Sun et al., 2018). Next, temperature plays a vital role in microorganism growth and metabolism, and it has a direct effect on their distribution (Ali & Okabe, 2015; Ma et al., 2016). In addition, the soil temperature is an essential factor in determining physical processes that occur in the soil and energy exchange and mass with the atmosphere, including evaporation and aeration processes. Soil temperature also affects biological processes such as germination seeds, seed growth and development, root development, and microbial activity in the soil (Dhadli et al., 2015). Two major environmental factors affecting soil organic matter decomposition and rice straw in paddy soils have been established as soil temperature and moisture (Carey et al., 2016). Microbes act as significant advantages and a significant element in ensuring the soil's efficiency and paddy growth. The rhizosphere is the locus for the soil microbes in plant roots (Hakeem & Akhtar, 2016). Therefore, related to their possible function as a plant growth regulator, interest in beneficial microorganisms in rice has grown for decades (Doni et al., 2015). The microbial population changes have been studied mainly in the soil environment state of carbon dioxide (Ren et al., 2015). Plants benefit from rhizosphere microbes because they provide nutrients and growth-stimulating hormones and suppress phytopathogens and increase resistance to environmental stress (Ding et al., 2019). Elevated temperatures can raise soil organic matter decomposition substrates through extra-cellular enzymes that break down macromolecular organic matter into the labile and low-molecular-weight organic mixture and induce microbial activity absorption soluble organic matter, resulting in higher rates of microbe’s diversion. Soil temperature has a significant impact on plant photosynthesis and paddy respiration than air temperature (Lin et al., 2017).

SOIL TEMPERATURE AND ROOT GROWTH

One of the critical physical indicators of soil, which affects the formation of its composition, as well as its carbon (C), nitrogen (N) and other biochemical cycles, is temperature (Liu et al., 2018a). Solar radiation is the primary source of surface temperature and is determined by a thermometer. As a result of radiant energy fluctuations and energy shifts in the soil surface, soil temperatures differ seasonally and regularly. Next, soil temperature may severely influence the absorption of nutrients and water, which can affect root development and microbial diversity (Sun et al., 2018). The colours of soil affect the soil temperature; for example, dark soil usually receives more heat and high soil temperature than light coloured soils. The differences were observed in the colour of horizon I at the organic paddy field. The soil temperature variability is influenced by the amount of solar radiation that a soil collects and receives. The soil temperature often changes as the solar radiation reaches the soil surface. Table 1 shows the summary of studies on the influence of solar radiation on soil temperature and paddy field dynamics.

Other than that, soil humidity refers to the quantity of water deposited between the soil pores. Soil humidity is highly dynamic due to soil surface evaporation, perspiration and percolation (Ebrahimi-Mollabashi et al., 2019). Soil moisture is a crucial component of a plant's water availability. It is used for planning and irrigation scheduling. Other than that, soil moisture variation can affect the pattern of irrigation and runoff in a paddy field. It also contributes to the deep percolation and evapotranspiration (Xu et al., 2017). Soil moisture is one of the main variables for changing water and heat energy by evaporation and moisture between the soil and atmosphere (Larson & Funk, 2016). Depending on the texture and distribution of soil pores, each type of soil shows variations in soil moisture characteristics. The texture of the soil is usually referred to as the number of fractions of land it contains. Air movement in the soil profile is influenced by moisture. In wet soil, heat transfer is higher than in dry soil with air in the pores. The amount of heat dissipation increases as moisture content grows.

MICROBIAL ACTIVITY IN PADDY FIELDS AND OTHER PLANTS

Rice plant-microbe interactions

Rhizosphere. Interaction of rice plants with microbes take place in the rhizosphere, phyllosphere, and endosphere, which are referred to as the rhizosphere, phyllosphere, and endosphere, respectively. The rhizosphere has received more attention than the other two domains; it is a thin layer of soil that surrounds plant roots and is only a few millimetres deep. Microorganisms, plant roots, and soil elements all interact in this dynamic microcosm (Mickan et al., 2019). Plants secrete various photosynthates chemicals into the rhizosphere through their roots, which attract and sustain microorganisms, forming mutualistic relationships (Venturi & Keel, 2016; Ahbar et al., 2024). Microbes in the rhizosphere help plants in various ways, including nutrient solubilization, storage, and absorption (also known as mobilisation, immobilisation, and weathering of minerals) the decomposition of obstinate organic materials (Pangesti et al., 2016).

Table 1. Studies about the influence of solar radiation on soil temperature and paddy field dynamics

Year	Authors	Title	Focus of study	Key findings	Relevance to soil temperature
2021	Sadawarti et al.	Effects of mulching on soil temperature in paddy fields	Studied how different mulching materials might influence soil temperature by altering solar radiation absorption	Paddy straw mulch showed lower minimum and maximum soil temperatures compared to black polyethylene	Studies showed the critical role of mulch in regulating soil temperature by modifying the dynamics of radiation
2023	Bwire et al.	Impact of environmental factors on rice paddy catchment under AWD irrigation practices	Investigated the mechanism on solar radiation interacts with alternate wetting and drying irrigation, focusing on hydrological and soil properties	When combine to AWD practices, solar radiation altered soil hydraulic conductivity and moisture retention, which affect the soil's thermal properties	Focusing on the role of solar radiation in increasing moisture and soil temperature by using AWD approach
2019	Hashimoto et al.	UAV monitoring and canopy reflectance simulation in paddy fields	Assessed the interactions between solar radiation with vegetation cover by using UAW simulations	Vegetative growth of paddy reflectance effect of microclimate, which alter the available energy from solar source for soil absorption and influencing productivity	Highlighting the indirect influence of vegetation on soil temperature through the interaction of solar radiation
2021	Vanitha et al.	Factors influencing paddy production	Demonstrated key variables, including solar radiation, which affect paddy production	Solar radiation is an important input for any variables exist, yield models which also indicates is centre of plant-soil interaction	Solar radiation affected soil temperature as part of crop yield determinants

Phyllosphere. The phyllosphere is the plant's aerial components, which are the most visible above ground. Microbes in the phyllosphere around, on, or inside the leaves and stalks help with nutrient and water cycling, among other ecological services (Bao et al., 2020), plant growth and resilience to biotic and abiotic stressors are also improved (Farré-Armengol et al., 2016). This is a dynamic microenvironment in which resident bacteria are exposed to various environmental conditions, including temperature, moisture, solar radiation, and elevation. These factors also have an indirect impact on phyllosphere microorganisms by causing changes in the plant's metabolism.

Endosphere. The endosphere is the microbial home located both above and below ground in the organs of plants. It covers the internal cellular systems of plants and their associated transport systems, where microorganisms can live (Schlaeppi & Bulgarelli, 2015). Endophytic microbes boost the health and performance of their host plants, as well as their response to biotic and abiotic challenges, once they become established in the inhabitants of their host plants (Doty, 2017). Figure 1 shows the rhizosphere, a small soil compartment where rice roots emerge and influence each other, called the rhizoplane. When rice soils are flooded, oxygen is released from the aerenchyma of rice roots, which promotes the formation of oxic zones around the roots (i.e., the rhizosphere), which are surrounded by anoxic ground soil. The surface of the rice roots is known as the rhizoplane (including root hairs). Inside the rice roots is a chamber called the endosphere.

Microbes have also been found to be excellent biological control agents for a wide range of phytopathogens. Farmers will be able to reduce the usage of hazardous chemicals to safeguard crops due to their efforts. Microbes have been observed to have a moderating influence on soil balances as low-cost biocontrol agents without hurting other beneficial species in the soil.

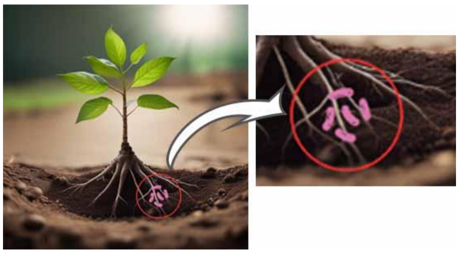

Figure 1. Rhizosphere is located around the roots of plant, rhizoplane area

Microbes maintain a rich and balanced soil environment by releasing micronutrients and macronutrients through nitrogen fixation, phosphate and potassium solubilization, and soil organic matter breakdown. Having a more excellent knowledge of the molecular and biochemical systems that produce these impacts can take advantage of these changes. Microbes can reprogram molecular signalling inside rice plants, improve plant growth, and suppress plant illnesses through processes such as the synthesis of growth-promoting chemicals (Pandey et al., 2016). Microbes can change the morphology and physiology of plants, improve their development and resistance, and change their gene expression patterns, among other things. In recent years, research into plant-microbial interactions has shed light on how certain microorganisms create endophytic connections with plants, beginning in their roots. Plant physiology and molecular signalling are influenced by microbial inhabitation to cope with a wide range of abiotic stressors (Harman & Uphoff, 2019). Table 2 summarizes the studies mentioned.

Table 2. Studies of microbial contributions to soil health, nutrient cycling and plant stress management in agriculture

Year	Author	Focus of study	Key findings
2018	Ab Rahman et al.	The role of microbes as biocontrol agent agents for phytopathogens	Microbes can reduce the use of hazardous chemicals by being biocontrol agents
2004	Benitez et al.	Microbial influence on soil balance as biocontrol agents	Contribute to soil balance at low cost
2022	Chen et al.	Microbial interactions with soil environments	Contribute to soil health without adverse effects
2014	Bhardwaj et al.	Microbial contributions on soil nutrient cycling	Reprogram molecular signalling
2016	Pandey et al.	Microbial effects on rice plants	Suppress plant disease through growth promoting compound
2019	Harman & Uphoff	Microbial interactions with plant physiology and stress management	Influence plant gene expression

Soil temperature affects the microbial at the root system

The role and function of soil microbes dramatically determine the successful sustainability of agricultural production systems. Soil microbes are responsible for various nutrient transformations in the soil related to soil fertility and soil health. The different soil temperature because of several factors reacts to the microbial activity at the root system. Soil microbial growth and activity temperature response such as respiration has focused on intensive research with a projected increase in temperature due to higher CO_2 levels inside the atmosphere (Bååth, 2018). One factor would be that temperature influences microbial activity, directly and indirectly, influencing other determinants of microbial activity in the soil, such as moisture and nutrient availability.

Influence of soil temperature on soil respiration

The soil microbial respiration temperature response is a vast source and an essential source of instability in climate forecasts (Liu et al., 2018b). Soil respiration refers to the transport of CO_2 from the soil to the air, primarily driven by soil microorganisms and plant roots (Mcewan et al., 2020). It is impacted by biological elements like plants and microbes, environmental elements like temperature, humidity, and pH, and human influences to a more significant level. Soil respiration rate decreases exponentially with increasing latitude and increases with increasing temperature. Soil respiration is one of the indicators of soil biological activity such as microbes, plant roots or other life in the soil. This activity is essential for the ecosystem in the soil. In soilrespiration, the use of O_2 and the release of CO_2, the respiration level can be determined by measuring the O_2 used by soil microbes. Respiration measurements in the field are performed by pumping soil air or covering the soil surface with a vessel of known volume.

Soil microbial respiration grows practically significantly with rising temperature over the usual range of soil temperatures, and several fields and laboratory investigations have shown a positive correlation between soil respiration and temperature (Smith et al., 2019). Rising global temperatures are anticipated to boost the rate of respiration of bacteria that break down soil organic carbon, resulting in a 40% increase in CO_2 emissions resulting from increased SOC breakdown (Auffret et al., 2016). Soil microbial respiration is adapted to temperature at physiologically altering individuals, and species turnover is adapted to temperature through developmental community adaptation (Dacal et al., 2019). Variations in the environment, such as changes in soil temperature and relative humidity, influence microbial respiration rate in the soil (Ye et al., 2019). Over the last several decades, most research has focused on the temperature reaction of microbial respiration within average temperatures, such as below 35 °C, and have found rapid growth in respiration with increasing temperature (Hamd et al., 2013). Even in cold climate soils, the rapid soil respiration rate increases when the temperature rises to roughly 40 °C or higher (Jian et al., 2016). Several experiments have been carried out to see how biochar affects soil microbial respiration in reaction to temperature changes (Chen et al., 2018) and how that reaction varies based on the characteristics of the primary microbes (Ng et al., 2015). According to Brookes et al. (2017), the rate of microbial respiration in the soil can be influenced by soil C quality and the type and activity of microbial communities.

Impact of soil temperature on microbial growth

The temperature has a significant impact on the activities and growth rates of microorganisms. Temperature fluctuations force microorganisms to react within their constraints. The most significant environmental element impacting microbial development and activity in soils is temperature, combined with moisture content. Microbes develop complex networks of exchanges that are constantly adapting to resource changes. An adaptation response is an exchange in the microbial community structure, physiology, or enzyme justification that has the effect of efficiently adjusting metabolic to a specific temperature (Nottingham et al., 2019). Traditional culture-based methods show that microbial species have different minimum, optimal, and maximum specific growth temperatures (Smith et al., 2019). Consequently, variations in soil respiration temperature sensitivity might come from changes in community makeup and specific temperature sensitivities. Indeed, widespread soil bacteria and archaea have shown continuous fluctuations in relative abundance in reaction to warming (Oliverio et al., 201). Soil bacteria have various functions in the nutrient cycle of all critical elements, including carbon, nitrogen, and phosphorus, which alters the structure and function of soil, allowing temperate crops to grow. Soil bacteria collaborate in a variety of growth activities. Negative plant-microbial interactions occur when pathogenic, symbiotic mutualists, and decomposers limit plant production, whereas positive plant-microbial interactions occur when the soil microbial population supports plant development and yield (Classen et al., 2015).

Microbial interactions with plant roots can be influenced by changes in microbial community composition throughout the soil profile. Recent research found that temperature affects the distribution of two essential cyanobacteria in topsoil on a continental scale, showing that temperature fluctuations may influence microbial diversity and distribution at the community level (Zhou et al., 2016). Warming's transient effects on soil communities are thought to result from increased microbial activity depleting labile carbon substrates, and the exchange of microbial communities adapt, change of structure, or limit biomass in response to environmental changes and substrate allocation (Kunkel et al., 2016). The explanation for the disparity in optimal temperatures might be because various soils were investigated employing respiration techniques and methods for measuring fungal and bacterial activity (Smith et al., 2019). However, at higher temperatures, the transducing of respiration rate and microbial growth cannot be ruled out, implying the need to compare these three different activity measures directly. In general, activity and growth rate rise with temperature until an ideal value is attained, at which point they quickly decrease owing to deactivation and dying (Johnston & Sibly, 2018). Diverse microbial species may have drastically different soil temperature preferences. When slow temperature fluctuations allow for selecting the best-adapted species, a microbial community fundamentally can adapt.

Mechanism of carbon distribution on microbial diversity

Soil carbon (C) stability has become a major global issue due to numerous global climate and atmospheric chemistry changes (Dhadli et al., 2015). On a global scale, soil retains twice as much carbon as the climate and surpasses the carbon in plants and the atmosphere combined. Because of its massive scale, even minor changes in the stability of inputs to and outputs from the soil C pool would impact atmospheric CO_2, either reducing or raising the effect of flaring fossil fuels. Understanding organic matter breakdown, variation, and sequestration in soils need a deeper understanding of how microbial taxonomy controls biogeochemical cycling, global warming, and ecosystem sustainability because soil C cycling is ultimately the product of microbial growth and activity (Zhang et al., 2020). Microorganisms control terrestrial carbon fluxes in two ways: they accelerate C release to the air via catabolic processes, limiting conveyance by stabilizing C into a harder decompose form. The majority of experimentation has been observed on microbial CO_2 origin, with less consciousness about microbial consumption and the generation of sequesterable products (de Almeida Fernandes et al., 2018). As a result, any experiments to control soils for stable C storage will need to conceive how to manage microbial-derived C in soil.

Soil organic matter is formed when plant biomass is fixed in the soil, allowing for carbon storage in terrestrial ecosystems. The amount of organic carbon in the soil is essential for soil fertility measures. Using various fertilizers with high carbon inputs, such as manure or crop residue integration, may help increase soil organic carbon sequestration (Qaswar et al., 2020). Soil microorganisms control soil physical and chemical properties, extend the variety and population of soil microbes, protect soil quality and fertility, and facilitate crop development (Zhao et al., 2017). Plant biomass that is fixed in soils are SOM contributes to ecosystem production and sustainability. Soil microbes heavily impact the group of organic carbon (SOC) in the soil. Rhizosphere activities governed nutrient cycling, such as SOM decompose and nutrient fluctuation, intimately linked to plant roots and their related rhizosphere activities, critical for paddy ecosystem function. Non-rhizosphere processes, on the other hand, are crucial to biogeochemical cycling and crop development. The proportion of growth and organic C absorbed in organic C was the soil microbial carbon (C) utilization efficiency (CUE). It was important in biogeochemical cycles and plant development. The amount of development and organic C consumed in organic C was known as the soil microbial carbon (C) utilization efficiency (CUE). It was a crucial systematic component of soil microbial group metabolism. The primary factors of exchange in SOM amount are abiotic environmental and edaphic adjustable, varieties of organic input, and biological activity (Fan et al., 2015).

Mechanism of soil temperatures effects on soil microbial

Soil temperature can influence microbial movement directly and indirectly by influencing other parameters such as soil moisture water quantity. High temperatures are linked to elevated microbial activity rates. Furthermore, changes in soil temperature have an impact on the composition of the microbial population. Temperature determines microbial activity, which stimulates plant growth, often overlooked while focusing on soil temperature (Wei et al., 2019). Differences in physical and chemical parameters along a soil depth gradient promote the establishment of diverse microbial communities. Changes in microbial communities' abundance, activity, and composition are typically linked to changes in ecological architecture, such as SOC mineralization (Creamer et al., 2015). Microbial data is increasingly being used in ecosystem process models to improve C and N cycle predictions beyond those based entirely on environmental data (Graham et al., 2016). Soil microorganisms, substrate accessibility and qualification, and environmental elements all affect the ecosystem activities (Dai et al., 2017). Not only is it desirable to maintain or increase global soil carbon stocks for soil purpose and agricultural production, but it is also a way for mitigating climate exchange. Priming, or the additional waste of soil-C due to the rise of labile substrates, has been associated with substituting in microbialcommunity composition. The microbial community's many functional species are invariably implicated in microbial controls on SOC synthesis, transition, and stability (Fan & Liang, 2015). Increasing CO_2 and other greenhouse gas concentrations are projected to create worldwide environmental changes such as temperature rises, which will negatively impact rice and maize output (Zhao et al., 2017) or limit the quantity of increase in food production demand. Increased CO_2 will directly affect crop photosynthesis, resulting in higher grain production; nevertheless, the magnitude of the CO_2 fertilization impact is one of the primary causes of variability in global agricultural output estimates (Schleussner et al., 2018; Hasegawa et al., 2019).

It has also been showing that levels of CO_2 in the atmosphere, either naturally or anthropogenically, might increase global surface temperatures by 1.8 to 3.61 °C by 2100 (Fahad et al., 2020). High temperature is projected to diminish soil water in some areas and produce drought in others, all of which will impact plant-microbe interactions, communities, and soil functions. As a result of present climate changes, the misuse of soil resources and poor vegetation management can take to erosion and the establishment of arid or semi-arid soils (Qaswar et al., 2020). Microbes are susceptible to temperature exchange limiting factors in other species. Temperature is one of the most critical factors that affect soil organic matter degradation and microbial groups. During the early phases of rice breakdown, for example, the temperature has a consequential impact on soil microbial phospholipids' phospholipid fatty acid concentration (Guixiang et al., 2016). When the temperature and CO_2 concentration are high, bacterial abundance increases (Bao et al., 2020); at various elevations, temperature changes would alter the structure and diversity of soil bacterial communities. Various bacterial taxa, including copiotrophic and oligotrophic groups, would react to increased nutrition availability induced by temperature changes in various ways (Deryng et al., 2016).

Changes in the enclosing environmental conditions (temperature rise) are particularly sensitive to the microbial decomposition of soil organic matter, which has the potential to alter enzyme kinetics and associated nutrient availability in the soil system through changes in resource allocation strategy and soil biota growth conditions (Hasegawa et al., 2019). The effective direction and net magnitude of C flux among the source-sink components of the global carbon cycle, as well as the status of soil C pools, available nutrient status, and soil C stock, may all be affected by the altered dynamics of soil microbial activity in a warmer environment, which may affect crop yields (Liang et al., 2017). The natural soil micro-environment and microbial community, which are frequently disrupted in the artificial field and laboratory warming experiments, are undervalued in certain studies (García et al., 2018). The largest ratio of respiration/soil C is found in soils with high native temperatures. By enhancing C allocation to plant and microbial biomass, high natural temperature- induced nitrogen (N) mineralization and microbial enzyme activity in soils have the potential to reduce soil C losses. However, this effect might not be enough to offset the increased potential C losses in soils at low native temperatures. Low-temperature soils have a larger capability to release carbon over time because carbon reserves do not degrade as quickly as carbon stocks in high-temperature soils. Increased temperature-induced respiration, along with substantial soil carbon stocks and low N mineralization rates, may make soils with a low native temperature regime more likely to create atmospheric CO_2.

THE CORRELATION STUDIES BETWEEN SOIL TEMPERATURE AND MICROBIAL DIVERSITY IMPACT OF SOIL TEMPERATURE IN PADDY FIELDS

Microorganisms produce various enzymes that aid in the breakdown of organic materials, affecting nutrient cycling and soil fertility (Jian et al., 2016). Even with a good understanding of the significant role of soil enzymes in the cycle of soil nitrogen in rice fields, the annual dynamics of enzyme activity and the factors that influence it are still insufficiently studied. In a Japanese rice field, annual fluctuations in enzyme activities involved in carbon (C), nitrogen (N), phosphorous (P), and sulphur (S) cycling, as well as soil physicochemical parameters, were investigated. In field conditions at a soil temperature of 2.2 – 28.3 °C, the activity of soil enzymes was assessed. The activity of β-D-glucosidase was chosen as a representative enzyme of the C-acquiring enzyme, which is explained by the participation of the enzyme in the hydrolysis of cellobiose (the main product of cellulose hydrolysis by cellulases) (Kunito et al., 2018). The change in enzyme activity stoichiometry associated with nutrient uptake can be explained by a resource allocation model for extracellular enzyme production. When nutrient uptake occurs, microorganisms will allocate more resources to enzymes to obtain the element that limits their productivity (Sinsabaugh & Follstad Shah, 2012). To capture the annual fluctuations in situ activity in the paddy field, enzyme activities were evaluated at the field soil temperature when the soil was collected. These findings imply that soil temperature significantly impacts in situ enzyme activities in paddy soil and that the stoichiometry of extracellular enzyme activity related to C, N, and P acquisition reflects soil nutrient availability. The correlation between four enzymes produced by soil microbes in rice shows the enzyme value at 0.8 and above, indicating a strong correlation as it is close to 1. Luo et al., (2020) shows the effects of root interactions on focal species growth of C. capsularis. The parameters temperature k-nearest neighbors showed the p-value is 0.0001, which is very significant and means that soil temperature have a high correlation with an enzyme produced by the microbial.

CONCLUSION

In cropping ecosystems, the soil temperature is one of the most important elements influencing nutrient availability and uptake. In the future, plant and microbial activity variations will be closely related to changes in soil temperature and moisture, and these micro-ecological interactions will be critical in nutrient availability and net ecosystem productivity. The different temperatures affected the root diameter, root weight, root length and microbial diversity significantly. However, due to the shorter crop growth time, an increase in temperature may reduce rice grain yields. Different soil temperatures disturb microbial activity, cell division, photosynthetic reactions, membrane integrity, growth, and productivity. Microbes determined to be beneficial are an essential component in maintaining soil quality and paddy production.

Changes in the surrounding environment (temperature rise) are susceptible to the microbial decomposition of soil organic matter, which, through changes in resource allocation strategy and growth conditions of the soil biota, contribute to altering enzyme kinetics and associated nutrient availability in the soil system. The response and tolerance mechanisms must be investigated at the molecular level to improve rice production. A functional genomics approach should be employed to understand better the molecular foundation of rice response to thermal stress tolerance. Various ecophysiological and genomics studies may aid in the understanding of the relationship between temperature stress and genotypes. To reduce crop losses, new rice varieties with improved tolerance over a wide range of temperatures at different stages are needed. Despite increasing temperature stress tolerance, heat and cold shocks continue to limit rice output, particularly in indica rice varieties. Fortunately, different rice cultivars have a wide temperature tolerance range, and cold-tolerant ecotypes are available for breeding. To determine the basic mechanisms of cold tolerance, an all-encompassing approach is required. To improve rice resistance to temperature shocks, different crop management strategies such as balanced crop nutrients and to modify the planting time should be investigated more in the future. To fully understand the impact of soil temperature in field situations, more research is required. The physiology of temperature-sensitive root mechanisms in rice and the interaction between shoot and root growth should be better understood to better understand. Because the effects of soil chemical and microbial activity were included in the soil temperature treatments in this study, it was necessary to separate these indirect effects from the direct sensitivity of the root growth process to changes in soil temperature.

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Author's statements

Contributions

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