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Micrometeorological Studies in Rice: A Review

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ABSTRACT

Rice is an important food crop cultivated all over the world and in India. There are different factors such as temperature, relative humidity, rainfall and solar radiation are influencing on rice crop production. Not only these factors, but also, some of the micro climatic factors such as canopy temperature, leaf temperature, soil temperature and stomatal conductance are also influencing on crop production. Microclimate, which refers to the climatic factors in the immediate proximity of the plants it controls and influences the physiological responses of the plants as well as the activities of energy exchange between the plant and its surroundings. It is expected that increased year-to-year yield variability in crop production will result from an increase in the frequency and severity of droughts and floods, as well as from irregular precipitation patterns.In order to promote food security and agricultural sustainability in this changing climate, it is necessary to use such microclimatic alterations in crop production in order to reduce the risk of extreme weather events and increase crop output. This study aims to increase crop output and land productivity through microclimate modification as a demonstration of the effectiveness and efficiency of growth factor utilisation. The detailed description of microclimate and its role with reference to rice crops are reviewed under this chapter.

Key words: Crop production, Microclimate, Rice, Solar radiation, Temperature.

As usual in climatology, a different number of climate variables are used to characterize a location's microclimate. These variables used to describe the thermodynamic and dynamic state of the atmosphere. They are mainly radiation, temperature, humidity, wind speed and pressure (density). The energy, momentum and mass conservation equations (dry air, water vapour and tract gases) determine the temporal and spatial distributions of the state variables. The components representing turbulent transport in these equations are particularly essential and receive a lot of attention in studies on microclimate because the flow in the area of the Earth's surface is often turbulent (Rotach, 2003). The microclimate is the localized, different in process of the surface layer such as energy exchange andradiation processes that response to ecological processes in plant growth, soil respiration, nutrient cycling, wildlife habitat, spread of diseases, insects and natural disturbances such as fire (Foken, 2008). Microclimates in the natural environment is created by changes in the environment in costal zones and difference in altitude of topographical regions (Kudryavtsev and Krasny, 2012). Microclimatology is the study of long term average and physical variability of climate variables in the lower layer of the atmosphere responds to the surface boundary layer conditions. Microclimate of a particular location is affected directly by the characteristics of the underlying surface (North *et al.,* 2014). The climate immediately above, within and in the soil root zone is referred to as the crop microclimate and it can be changed by daily management activities at different time scales (Vatistas, 2022). Artificial management of the plant environment to maintain ideal conditions for improved plant growth and agricultural output is a future direction in agro meteorological research. For managing the sensitivity to extreme weather and climatic risks in agriculture,

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microclimate modification techniques can be helpful adaptive measures. Crop development and yield performance are improved by farm-level adjustments and protected cultivation through, among other things, adjusting the physical environment, sun radiation, soil temperature, soil moisture and wind speed. The transpiration and leaf-to-air transfer processes are closely linked to the within-canopy microclimate, which means that conditions within canopies both start dictating the leaf energy balance of the plant (Bramer, 2018).

Methods for modifying microclimate

Glickman (2000) stated that good structure in soil had resisted wind and water erosion, as well as increased water percolation and storage capacity. The low soil temperatures inhibited water uptake by plants, nitrification and reduced the soil fertilityand increased when air temperatures are higher. Microclimate was modified for short period during the day time through sprinkler irrigation while this modification is minimum during night time irrigation (Playán *et al.,* 2005 and Cavero *et al.,* 2009). The microclimate under field conditions was modified through two consecutive sprinkler irrigation intervals in wheat and corn (Liu and Kang, 2006). Zhao *et al.* (2012) reported that the microclimate within the sprinkler irrigation could be modified during irrigation and the effect was continued for ten to twenty hours after the application of sprinkler irrigation. Crop plants can be given the best environment possible through microclimate modification. By making small alterations to crop management, we can alter the agricultural microclimate without spending a great deal of money. Such adjustments can enhance the microclimate and increase crop development and productivity (Mahi and Kingra, 2013). Nawarathna *et al.* (2014) inferred that land surface temperature (LST) was lesser closed to the wetland and indicating the microclimatic regulation effect of wetlands.

Kaur *et al*. (2014) reported that canopy temperature measurements are made to estimate the plant water status and to schedule irrigation under modified microclimate. Soil moisture is one of the most important microclimate determinants. The thermal conductivity and heat capacity of the soil is greatly increased in presence of soil moisture because moisture is the responsible factor for transport of heat (Bonan, 2015). pplication of mulching practices reduced soil evaporation, conserves soil moisture, suppresses weed growth, controls soil structure and temperature and influences soil microorganisms. The control soil environments under various mulching conditions caused a greater influence on crop yield, productivity and water use efficiency in sugar beet (Kader *et al.,* 2017).

Effect of modified microclimate on temperature in rice

Ponded water layer in the field buffers temperature extremely at the growing point of the rice plant. The daily change in temperature of water body decreased with increase in water level (Confalonieri *et al*., 2005). High temperature stress in plants is a complex function of intensity of duration of light and rate of increase in temperature (Wahid *et al*., 2007). The high vapour pressure deûcit (VPD) present in the rice assisted the plants to avoid heat stress and to maintain the microclimate below critical levels by efficient transpiration cooling, rather than by high temperature (Weerakoon *et al*., 2008). In warm nights during wet season, water temperature was similar to air temperature. Similarly, in cool nights water temperature was warmer by 4°C than air temperature due to the re-radiation of the earth. Higher night temperature and elevated carbon dioxide during the reproductive growth period affected rice growth and yield (Cheng *et al*., 2008). During the day time, the rice canopy temperatures of the mulching treatments were lower than that of bare cultivation and during the night time, the rice canopy temperatures of the mulching treatments were lower than that of the atmospheric temperature due to flooeded conditions. However, there was no significant difference between different treatments (Zhang *et al*., 2011). The influence of water surrounded on meristem of rice plant is directly related to water temperature and had a larger influence on plant growth than air temperature. In less night temperature, ponded water layer protected the rice plant meristem from cooling (Stuerz *et al*., 2014). Tiller number at flowering stage was negatively correlated with maximum temperature independent of irrigation treatment (Stuerz *et al*., 2014). Stomata closure, which prevents water loss when the soil is water-scarce, is one of many elements that affect this regulation. Rice flag leaf stomatal conductance, net photosynthetic rate and soluble protein content all decline in response to high temperatures. Heat-tolerant cultivars, on the other hand, have better photosynthetic capacities than more susceptible types as well as higher root vigour and leaf antioxidant protection system capacities, all of which boost their tolerance to high temperatures (Wang *et al.,* 2019).

Effect of modified microclimate on canopy temperature in rice

The natural environmental circumstances in which the rice grows, rice variety features and cultivation practises are the main factors affecting rice canopy temperature (Penfield, 2008). Infrared thermography may be a simple method for evaluating varietal difference in stomatal conductance through canopy temperature under cloudy conditions (Takai *et al*., 2010). Zhang *et al*. (2011) indicated that the difference of canopy atmosphere, temperature at noon reflected the status of rice water deficit. At heading stage, canopy temperature among different treatments such as plastic film mulching andstraw mulchingwas higher (0.71 and 0.43, respectively) than that of bare cultivation. The mulching cultivation significantly reduced the canopy temperature especially during high temperature period. Dass and Chandra (2013) reported that canopy air temperature was significantly correlated with leaf area index, total dry matter, biomass and grain yield. Thermodynamic characteristics and physiological responses to the environment govern the temperature of the rice canopy (Schymanski *et al.,* 2013). The four processes of conduction, convection, radiation and evapotranspiration of latent heat, as well as the heat conduction inside tissues, are all part of the thermal characteristics of rice. Rice plants typically absorb heat from the sun and long-wave radiation from items in their environment, such as the soil and the sky and produce heat energy through metabolic activities (Pieruschka *et al.,* 2010). According to Karwa *et al*. (2020), transpiration affects canopy temperature in hot climates and provides a theoretical foundation for determining high-temperature heat damage.

Effect of modified microclimate on soil temperature in rice

Tung *et al*. (2006) reported that direct burning of paddy straw in the rice field strongly changed the soil temperature especially, on the top layer of the soil. The increased soil temperature of 75°C and 89°C was observed in top 0 to 2 cm of the soil by dispersive and intensive rice straw burning and these causes decreased number of micro-organisms in soil. Cheng *et al*. (2008) reported that the differences of daily average air and soil temperatures between the high and low night temperature treatments were 3.8 and 4.2°C respectively. After the heading stage, water and soil temperature affected grain filling in rice (Arai-Sanoh *et al*., 2010). Small difference in soil temperature (0.3°C) was observed on 40 days after irrigation in the rooting zone of rice grown in pots as well as in field. However, the difference was small, because of growth and development was similar in both pots and in open field environmental conditions. Nicholson (2013) reported that the sandy soils had higher thermal conductivity, compared to the clayey soils with lesser thermal conductivity. The temperature at the soil surface was lower and leaf expansion rate was reduced at night temperature under non flooded conditions in rice (Stuerz *et al*., 2014). Soil temperature and moisture have been identified as two key environmental factors regulating the decompositions of soil organic matter (SOM) and of rice straw in paddy soils (Hussain *et al*., 2015). Higher soil temperatures were negatively affect plant growth, while extreme temperatures can stall biological processes of micro-organisms (FAO, 2016). Gaihre *et al*. (2016) concluded that optimum soil temperature for methane emissions in the tropics was between 34 and 35°C and reported that temperatures beyond this appears to decreased in methane emissions.

Effect of modified microclimate pn relative humidity in rice

More than 85 per cent of relative humidity with higher temperature of more than 35°C is the most serious level for high sterility in rice (Weerakoon *et al*., 2008). Ohsumi *et al*. (2008) reported that in the afternoon, decreased air humidity caused a decline in leaf photosynthetic rate of rice grown under irrigated conditions. Zhang *et al*. (2011) reported that under mulching cultivation in rice, provided a good favourable microenvironment (canopy temperature and relative humidity) for the growth and development. Kaur *et al*. (2014) observed that the relative humidity varied within the rice canopy at different stages during its growth and development. At flowering stage, the relative humidity within the rice canopy was higher than the panicle initiation stage during the both the years (2012 and 2013) of *Kharif* season. During 2012, higher relative humidity of 92.8 per cent was recorded in flowering stage in conventional planting method. The optimum relative humidity for rice cultivation lies between 60 and 80 per cent (Nguyen *et al*., 2016).

Effect of modified microclimate on wind in rice

Ishimaru *et al*. (2008) reported that the wind pressure on the leaf blade was larger than on the other parts present on the rice plant. Sridevi and Chellamuthu (2015) observed that wind velocity at tillering stage, had a positive significant correlation with grain yield and the effect with straw yield was positive but was non-significant. Strong winds caused leaf breakage and delay in crop maturity. Wind speed during active tillering to heading stage had a significant negative correlation with number of panicles per plant and straw yield (Sridevi *et al*., 2011). Wind speeds of 35 to 40 km/h caused the WS genotype to have a high percentage of dropped grains (25.7%) and unfilled grains (77.3%), as well as a low grain index (20.8 g) (Herdhata *et al.,* 2022).

Effect of modified microclimate on light interception in rice

SRI had a larger facilitation of individual plants and resulted in better light distribution, taller plants, larger total leaf area and high dry matter content compared to conventional method. (Sinclair and Cassman, 2004) revealed that in SRI cultivation, very low plant densities would lead to poor light interception, whereas high plant density is a pre-requisite for better light interception, growth and yield. Haque *et al*. (2006) reported light interception in rice at heading stage was higher and increased with nitrogen levels. Baloch *et al*. (2006) observed that leaf area index is an important factor which directly related to the interception and incident of solar radiation and closely related to final grain yield. Ahmad *et al*. (2008) stated that total dry matter and accumulated intercepted photosynthetically active radiation were linearly related with yield of rice andintercepted photosynthetically active radiation (IPAR) in rice was varied from 1.18 g M/J to 1.94 g M/J at different locations of conventional rice belt in Pakistan. The difference between water and air temperature was lesser after the closure of the canopy when most of the solar radiation is intercepted by plants (Jamali *et al*., 2008). The scavenging of reactive oxygen species and the water potential in cells can both be maintained by low light tolerance genotypes. Due to the encouragement of antioxidative enzyme activity and osmotic control, this serves to limit the negative effects of low light on plant physiological metabolism. While types that are sensitive to low light exhibit cell membrane damage (Liu *et al.,* 2012). Kaur *et al*. (2014) observed that photosynthetically active radiation (PAR) interception was higher by five per cent in bed planting method compared to the conventional planting. The rice crop transplanted on 15 June during both the cropping season (2012 and 2013) Punjab Agricultural University, Ludhiana, India, had higher PAR interception in the bed planting method by 68.8 to 83.9% compared to the conventional planting method (53.8 to 83.6%).

Effect of modified microclimate on physiological leaf gas exchange parameters in rice

Yamada and Xu (2001) suggested that the physiological parameters such as chlorophyll fluorescence are the ratio of variable fluorescence to maximum fluorescence and the base fluorescence correlated with heat tolerance. Photosynthetic characters of rice are affected by solar radiation. Grain yield increased linearly with plant population (Ahmad *et al*., 2008). Uphoff *et al*. (2009) stated that the transpiration rate in SRI was lower by 16 per cent than conventional practices (7.59 mmol/m^2/s). Takai *et al*. (2010) reported that leaf photosynthetic potential is a major factor for determining crop yield through stomatal conductance as well as leaf nitrogen content (Rubisco protein content). Rice plants under mulching cultivation showed a stronger transpiration and lower leaf temperature, thereby high temperature stress on the rice plant which improved by increasing the photosynthetic rate (Zhang *et al*., 2011). Dew present on the surface of the leaf absorbed water and reduced the transpiration rate (Tomaszkiewicz *et al*., 2014).

Effect of modified microclimate on photosynthetic rate in rice

In non-flooded conditions of rice, water temperature affected the plant growth, leaf photosynthesis, growth rate, spikelet sterility and yield (Shimono *et al*., 2002 and Ainsworth, 2008). Ali and Talukder (2008) reported that photosynthetic activities and assimilate portioning resulted good yield in wide spaced rice fields. Uphoff *et al*. (2009) observed that SRI had higher net photosynthesis of 23.15 mmol/m^2/s compared to conventional practices (12.23 mmol m^2/s). Photosynthetic response curves in light indicated that the variety (Takanari and TUAT1-56a) had a higher photosynthetic rate and stomatal conductance under low irradiance of solar radiation of 500 µmol/m^2/s (Takai *et al*., 2010). Zhang *et al*. (2011) studied different mulching methods such as plastic film mulching, straw mulching and liquid film mulching which significantly affected the net photosynthetic rate of the uppermost three leaves of upland rice. During the whole growth period, the leaf net photosynthetic rates of the mulching treatment was higher (11.29 µmol m^2/s) at milky ripen stage followed by the full heading stage (10.80 µmol m^2/s). A vital natural resource, light regulates plant development and production. In photosynthesis, photoperiodism and photonasty, it plays a very important role. Agriculture involves essentially the process of utilizing solar energy, aided by water and nutrients for the growth of the plants (Fageria, 2013). The occurrence of overcast, rainy clouds and low light intensity has become a common issue due to the acceleration of global warming. It is now known that low light stress impacts each component of vegetative growth, including photosynthesis, dry matter accumulation and partition, plant height, tiller number, root growth, stoma regulation and chlorophyll formation on rice production and quality (Xiu *et al*., 2013).

Effect of modified microclimate on leaf temperature in rice

Canopy temperature was closely related with leaf temperature measured with portable photosynthesis system. The leaf temperature remained lesser than air temperature in all four varieties (Takani, Habataki, Koshihikari and TUAT1-56a) of rice by 13°C because of radiative heating of air molecules in the atmosphere (Takai *et al*., 2010). In a day hours, leaf elongation was increased with increase in temperature but, it was higher during the night and decreased with increasing evaporative process. Meristem temperature up to 30°C during the night or with very low evaporation increased leaf elongation, whereas it decreases at higher temperature (Stuerz *et al*., 2014).

Effect of modified microclimate on rice production

Aggarwal *et al*. (2000) found that the date of transplanting played an important role for obtaining optimum rice yields by influence on the temperature at grain filling and maturity stages on the cumulative heat units and root growth. Mulching cultivation had increased soil temperature, preserved moisture, promote the decomposition and release soil nutrients, increased dry matter accumulation and increased the yield formation of rice (Yang *et al*., 2002). Rice grain yield had declined by 10% for each 1°C increase in minimum temperature in the Philippines and yields increased roughly by ten per cent per unit increase in solar radiation up to 21.5 MJ/m^2/day of radiation (Peng *et al*., 2004). Rice yield was highly infiuenced by genotype while seed quality traits such as seed leachate conductivity, potential seed longevity, percentage seed germination and proportion of seed discoloration under field conditions were infiuenced more by environmental factors, *i.e.,* temperature (Krishnan and Rao, 2005). Arai-Sanoh *et al*. (2010) reported that higher soil temperature before heading stage influenced plant growth and grain quality. During panicle initiation stage, yield and yield components were negatively influenced by higher soil temperature of 37°C. The yield components of rice were significantly improved under mulching cultivation, with plastic film mulching recorded higher grain number/ panicle, seed setting rate and a yield increase of 16.81 per cent compared with the bare cultivation. In straw mulching, increased effective panicle number and 9.59 per cent increase of total yield compared to the bare cultivation (Zhang *et al*., 2011). The rice canopy temperature increased with the decline of soil moisture and the temperature increased by 3 to 4°C under heavy stress. The canopy temperature at the flowering stage, was negatively related with grain yield and seed setting rate (Pandey, 2013). Rice leaves are the most important photosynthetic organ and the yield formation is essentially the accumulation and distribution processes of photosynthetic products (Zou *et al*., 2011). Coast *et al*. (2015) reported that increased night temperatures during the crop growth stages, especially during reproductive and early grain filling stages of rice led to reduction in biomass, grain yield and quality.

Effect of modified microclimate on leaf growth characters in rice

Storage of grains resulted in numerous changes in chemical and physical properties of rice (Geiger *et al*., 2009). Leaf expansion rate was compared under different irrigation treatments could resulted in sensitivity of the rice to soil water deficit is similar to that of maize (Parent *et al*., 2010). Kaur *et al*. (2014) stated that rice productivity was more when it is exposed to the direct sunlight of optimum intensity and the quality of the light is essential for normal photosynthesis, plant growth and development. Dry matter content depended on degree of exposure to the sunlight and incidence of solar radiation. Stuerz *et al*. (2014) reported that leaf area was reduced under non flooded conditions.

CONCLUSION

All the favourable parameters for the crop growth in rice are concerned by the atmospheric boundary and planetary layer interactions (microclimate). Microclimate was modified due to the alteration in spacing and it influences the growth and yield of rice varieties. According to predictions, there will be more instances of unexpectedly high temperatures, which might put the supply of food at risk. Therefore, by identifying the management strategies, choosing tolerant genotypes and breeding suitable rice cultivars, losses in rice production might be prevented. Therefore, it is urgently necessary to understand the physiological and genetic mechanisms and create heat-tolerant rice varieties in order to increase rice production quality, quantity and stability under a variety of environmental conditions. The yield losses will also be minimized through the adaptation of resistant genotypes of rice cultivars. However, care should be taken to ensure that increasing plant tolerance to high-temperature stress don't have negatively impact yield or quality attributes. All stages of rice growth are negatively affected by high temperatures, but the anthesis stage is the most vulnerable because even a small rise in temperature can have a big influence on yield.

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Declaration of competing interest

The authors declare that they have no conflict of interest.

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