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Exploring the landscape of contemporary crop micrometeorology: A bibliometric investigation

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ABSTRACT

Micrometeorology plays a pivotal role in advancing our understanding of agricultural systems by unraveling intricate interactions between climate dynamics and crop performance. This article presents a comprehensive analysis of the literature published on crop micrometeorology and indexed in Scopus database from 2000 to 2023. The query yielded only 146 documents, which were subsequently subjected to analysis using an R-based bibliometric tool to assess annual scientific production trend, document types, citation, and keyword analysis. The results revealed zero growth rate of the topic with an average 47.36 citations and total citation of 6536 in the analysis period. USA dominates the number of publications (28.1%), followed by China (17.8%), Japan (11.6%) and Australia (8.9%). India stood at 10^{th} position with only 8 documents contributing 5.5% of the total publications included in the study. The key domains of current research in the realm of crop micrometeorology identified through bibliometric analysis were evapotranspiration, energy balance, gas emissions, and modelling based studies, which are discussed in details in the article. As climate change and global food security becomes more critical, this analysis highlights the role of micrometeorological works within the realm of climate change and crop studies.

Keywords: Eddy covariance, Evapotranspiration, Bowen ratio, Emissions, Flux, Model

The study of micrometeorology encompasses the examination of radiant energy, momentum, and mass transfer within the atmosphere, specifically focusing on the weather conditions at the scale of plants, including trees, and animals, including humans (Monteith and Unsworth, 2013). This area of environmental physics has experienced significant advancements since the 1960s, primarily due to the development of advanced instrumentation and sophisticated systems for collecting and analyzing field measurements. Crop micrometeorological research plays a crucial role in understanding and optimizing agricultural systems by studying the interactions between crops and the surrounding atmospheric conditions at a small spatial scales less than 3 km and time scales of 1 h or less (Stull, 1988). This field of research provides valuable insights into various aspects of crop growth and development, allowing farmers, agronomists, and scientists to make informed decisions regarding crop management practices. This article aims to provide an overview of the significant progress made in understanding the complex interactions and processes occurring within the microscale environment. By delving into the intricate dynamics of micrometeorology, researchers have gained valuable insights into the exchange of energy, momentum, and mass between the Earth's surface and the lower atmosphere. These advancements have been facilitated by a combination of advanced measurement techniques, innovative modeling approaches, and the integration of interdisciplinary research efforts. In this article, we will highlight key findings, methodologies, and emerging trends that have shaped the field of crop micrometeorology in the 20^{th} century, emphasizing the implications for various applications for agricultural and climate change studies.

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MATERIAL AND METHODS

Since we are focused on the progress made in the 20th century so to discuss the recent studies first we performed a bibliometric analysis of the journal from 2000 to 2023 using the Web of Sciences (Scopus) database, chosen mainly for its quality standards, broad coverage in the collection of information and excellent coverage of micrometeorological journals. After thoroughly reviewing of the literature, we have decided to use the query "micrometeorology" AND "crop" as the final search query to restrict our analysis only to agricultural crops. Using the query: ((TITLE-ABS-KEY (micrometeorology) AND TITLE-ABS-KEY (crop)) AND PUBYEAR > 1999 AND PUBYEAR < 2024 AND (LIMIT-TO (LANGUAGE,"English"))), a total of 146 scientific documents obtained were used in the bibliometric analysis. The bibliometric analysis was performed using the R software version 4.3 (R Core Team, 2023).

RESULTS AND DISCUSSION

General Overview of the Data

The general overview of the retrieved data is presented in Table 1. Literature searched in Scopus database on recent micrometeorological work using the query mentioned in the methodology section yielded only 146 published documents between 2000 and 2023. In addition, 66 sources (journals, book chapters, proceedings, etc.) published documents on micrometeorology. A very interesting observation in the analysis is that the average annual growth rate of the topic is 0 %, indicating no significant growth in micrometeorological publications in recent years. However, the limited number of literature available received an average 47.36 citations. The total citation count stood at 6536 on 1 August 2023.

Only 9 documents were prepared by single author. The average number of co-authors per document is 4.9, signifying a notable level of collaboration. A higher count of authors per document typically reflects interdisciplinary involvement, as experts from various fields team up for thorough investigations. This idea is reinforced by the international co-authorship rate of 34.93%, indicating widespread collaboration among authors from different nations. This trend often arises in research with a global focus, contrasting with studies of regional significance.

Across various document categories, the primary type is the article or original research paper, accounting for 88.36% of the overall document tally. It is trailed by conference papers at 8.21% and book chapters at 6.74%. The review articles on the current topic are only 1.36 %. Annual scientific production in micrometeorology is represented in Fig. 1. Throughout the literature analysis period there is no significant trend in number of publications, the curve followed an irregular pattern showing very slow development. Although in 2016, maximum number of documents were published (n= 14), it was short-lived and the number of documents did not exceed more than 6 till the time of this analysis.

As depicted in Fig. 2, The USA leads in terms of publications with the highest count (n = 41), representing a substantial 28.1% of the total publications encompassed by the study. It is followed by China (n = 26), Japan (n= 17) and Australia (n= 13) with 17.8, 11.6 and 8.9 % of the total publications included in the study. India stood at 10th position with only 8 documents contributing 5.5% of the total publications included in the study.

Most relevant abstract words including both trigrams and bigrams and author's keywords are depicted in Table 2. latent heat flux , soil water content , soil heat flux, surface energy balance , and eddy covariance ec are the top 5 most trigrams in abstract of the published literature . Similarly, heat flux, latent heat, eddy covariance, energy balance and air temperature are the top 5 most bigrams in published abstracts. The author keywords micrometeorology, evapotranspiration, eddy covariance, energy balance and remote sensing are top 5 keywords cited. From the analysis of keywords, it is evident that the recent micrometeorological studies are focused more on studying the energy balances using different flux measurements using the eddy covariance. Evapotranspiration is another major topic covered in most of the recent studies. Apart from this words like soil water, crop coefficient, growing season, carbon dioxide, ammonia, nitrous oxide, greenhouse gas and crop model reveals how the publications have tried to focus linking micrometeorological studies with crop and climate change for sustainable agriculture for food security. To further discuss the recent literature, they were separated into the following three sections based on the bibliometric analysis: Evapotranspiration and Energy balance, Gas emissions, Modelling and Crop monitoring.

Evapotranspiration and energy balance

The precise measurement of water vapor movement within agroecosystems has been a longstanding requirement, driven by drought occurrences and the ongoing depletion of groundwater on a global scale. Multiple methods have been employed to assess water vapor fluxes in these systems, encompassing remote sensing methods, direct on-site measurements, and micrometeorological modeling systems (Dhungel *et al.,* 2020). Evapotranspiration (ET), a crucial factor for refining irrigation practices, maximizing water efficiency, and improving the quality of crops (Kustas *et al.,* 2018). In start of the 20th century researcher's evaluation of energy balance was done using the lysimeters. The lysimeters were used to directly measures the loss of surface water from exposed soil and/or vegetated areas (Evett *et al.,* 2016), which accurately determines ET and enables the assessment of other components of surface energy balance like net radiation (Rn), sensible heat flux (H), and soil heat flux (G). Typically, net radiation and soil heat flux are directly measured, while sensible heat flux is derived as the difference between ET, Rn, and G. Zapata *et al.,* (2002) and Zhang *et al.,* (2008) used similar approach to evaluate ET of the wheat crop. The combination equation of Penman–Monteith was modified by Allen *et al.,* 1998 and has been adopted by researchers for reference evapotranspiration estimation. The Penman–Monteith method calculates ET directly from principles related to energy conservation and air diffusion (Li *et al.,* 2014). The process-oriented Penman-Monteith (PM) approach stands as one of the most widely accepted and utilized techniques for assessing ET in the considered time period. Landeras *et al.,* (2008) used these equations for ETo determination and also for developing ANN models for measuring the same. Marin *et al.,* (2011) utilized the PM method for studying

Table 1: General overview of the bibliometric data on crop micrometeorology.

Description	Results
Timespan	2000-2023
Sources (Journals, Books, etc)	66
Documents	146
Annual Growth Rate %	0
Average citations per doc	47.36
References	6536
Authors collaboration	
Single-authored docs	9
Co-Authors per Doc	4.9
International co-authorships %	34.93
Document types	
Article	129
Book	1
Book chapter	2
Conference paper	12
Review	2

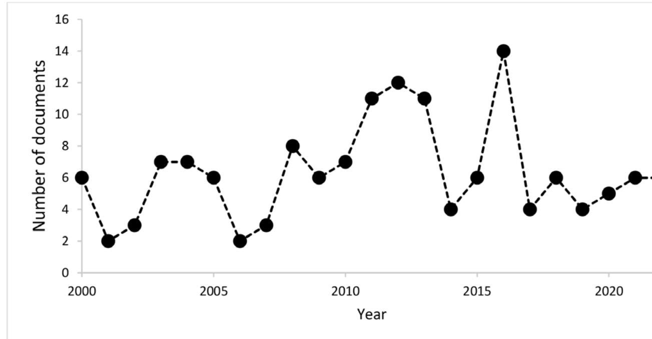

Fig. 1: Annual scientific production of literature on micrometeorology from 2000 to 2023.

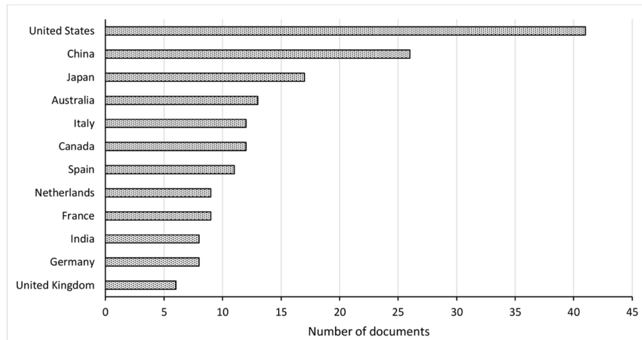

Fig. 2 : Top 12 countries with the highest productivity on micrometeorological studies.

the irrigation requirements as well as the interconnection between transpiration and the atmosphere in a citrus plantation in the southern region of Brazil. The FAO Penman–Monteith is still very reliable and used by several researchers for studying evapotranspiration in different crops like maize (Wang *et al.,* 2020), eggplant (Baylon *et al.,* 2021), rice (Kumari *et al.,* 2022) etc using micrometeorological measurements.

Advancements in technology have enhanced the assessment of ET, aided by the ability to monitor micrometeorological factors more closely. In the pursuit of an optimal approach to quantify ET from agricultural systems, various other techniques of different levels of complexity have also been documented in the literature. These methods include energy balance (EB), Bowen ratio (BR) and soil water balance, as well as eddy covariance (EC), field lysimeter and sap flow measurements techniques. Among these approaches, both EC and EB have emerged as scientifically sound and easily applicable choices for obtaining precise ETc data in agricultural fields. (Baldocchi, 2003; Parent and Anctil, 2012; Uddin *et al.,* 2013). The EC and Bowen-Ratio Energy Balance (BREB) techniques serve as valuable sources for validating models of evapotranspiration, which are derived from either on-site measurements or satellite observations (Soegaard *et al.,* 2003). The BREB setup is a straightforward and cost-effective design, relying on temperature and water vapor gradients across two levels, with minimal spatial requirements (Balbontin-Nesvara *et al.,* 2011). In contrast, the EC system is more intricate and costly which functions by establishing the relationship between fluctuations in the concentration of a variable (such as water, CO_2, or momentum) and the vertical wind speed fluctuations. This approach is considered a standard in micrometeorological techniques (Monteith and Unsworth, 2013) and has been applied in studying agricultural crops, forests, and natural vegetation. These methodologies have been tested and verified across various plant types with good accuracies. Balbontin-Nesvara *et al.,* (2011) quantified and compared the ET from a vineyard canopy through BREB and EC methods. Both methodologies provided comparable estimations for both daily and cumulative ET, enabling the prediction of variations in the crop coefficient throughout the growing season. However, the BREB system slightly overestimated the fluxes as compared to the EC system. Uddin *et al.,* (2013) demonstrated that employing the energy balance technique with the eddy covariance approach for calculating the instantaneous Bowen ratio not only accurately measures the variable total evapotranspiration rate over various surfaces during sprinkler irrigation for a cotton crop, but also effectively quantifies the notable influence of advection on evapotranspiration. Chen *et al.,* (2016) documented the fluctuation on a seasonal and annual variations of radiation, energy fluxes, and energy balance closure across a rain-fed cropland located in the semi-arid region of the Loess Plateau in Northwestern China utilizing the data from meteorological towers and the BREB approach they reported that soil moisture played a primary role in influencing the radiation budget and energy distribution. The albedo exhibited a negative linear correlation with soil moisture, with agricultural activity impacting the relationship and variability between albedo, soil moisture, and energy partitioning dynamic. Anapalli *et al.,* (2018) quantified soybean evapotranspiration using EC and EB methods in the Mississippi Delta region. They presented a new approach for compensating the unaccounted energy using the BREB and EC corrected latent heat methods.

One of the remarkable trends during this timeframe is the increasing integration of micrometeorological techniques. Researchers have conducted comparative studies, evaluating the strengths and limitations of each approach in different contexts. These efforts have led to a more comprehensive understanding of ET dynamics and improved the reliability of ET estimates. Zhang *et*

Table 2: Most relevant abstract words and author's keywords**.**

Abstract Words (Trigrams)	OC	Abstract Words (Bigrams)	OC	Author Keywords	OC
latent heat flux	25	heat flux	53	micrometeorology	40
soil water content	19	latent heat	43	evapotranspiration	29
soil heat flux	11	eddy covariance	42	eddy covariance	19
surface energy balance	10	energy balance	42	energy balance	9
eddy covariance ec	9	air temperature	38	remote sensing	7
eddy covariance technique	9	soil water	35	bowen ratio	6
latent heat fluxes	9	heat fluxes	30	crop coefficient	6
eddy covariance method	7	growing season	26	ammonia	5
pressure deficit vpd	7	net radiation	24	climate change	5
vapor pressure deficit	7	bowen ratio	20	nitrous oxide	5
vapour pressure deficit	7	crop evapotranspiration	19	surface energy balance	5
energy balance closure	6	water content	19	water balance	4
heat flux le	6	wind speed	19	advection	3
maize zea mays	6	kc values	17	canopy temperature	3
net radiation rn	5	micrometeorological methods	16	carbon dioxide	3
net radiative loss	5	water vapour	16	crop model	3
north china plain	5	soil moisture	15	penman-monteith equation	3
soybean glycine max	5	surface energy	15	greenhouse gas	3

OC : Number of occurrences

al., (2011) used a hybrid approach involving micrometeorological and stable isotope techniques to examine evapotranspiration and soil water behavior within a winter wheat agro-ecosystem. This investigation utilized stable isotope mixing models in conjunction with data from eddy covariance evapotranspiration estimates and micro-lysimeter evaporation measurements to differentiate various components of evapotranspiration and analyze the changing depths of root water uptake over time. Consoli and Papa (2013) based on their analysis of a long term energy balance monitoring programme coupled with measurements of sap flow and additional biophysical data for estimating ET in cultivated orange, recommended the BREB method to resolve the energy closure issue of the EC technique. Saitta *et al.,* (2020) investigated the precision of crop evapotranspiration (ET_c) for Citrus trees in a semi-arid Mediterranean climate using eddy covariance (EC) and sap flow heat pulse velocity (HPV), as well as modeling techniques of single and dual crop coefficient (K_c) approaches proposed in FAO-56. The outcomes of the analysis revealed that both single and dual K_c methods yielded similar ET_c estimations although they overestimated ET_c measured. In essence, the evaluated techniques captured trends in ET_c, yet the choice of the most suitable method hinges on the particular crop and study site characteristics.

It is well-established in the literature that turbulent fluxes measured using EC systems often deviate from the available energy, resulting in surface energy imbalance. As a result, acquiring a qualitative comprehension of how diverse vegetation types and climatic factors influence this phenomenon of 'nonclosure' holds paramount importance. Zhou and Li (2019) studied the energy balance across various ecosystems, including alpine meadows, deserts, shrubs, and crop to examine the energy balance closure ratios (EBR). EBR values range from 0.53 to 0.99, with an average of 0.84. The study finds consistent trends in EBR values with factors like friction velocity, thermally induced turbulence, atmospheric stability, and others. There's a negative relationship between EBR and surface temperature variations. Turbulent kinetic energy plays a crucial role in EBR variations, suggesting its potential as an indicator for energy balance closure correction. Dare-Idowu *et al.,* (2021) also examined an exclusive dataset of EC flux measurements spanning 8 consecutive growth seasons for corn, wheat, and rapeseed grown in the southwestern region of France and reported that the impact of each site on the energy balance closure was more pronounced as compared to the influence exerted by crop type and growth stage. Closure was additionally evaluated across different atmospheric stability scenarios and wind sectors, revealing a higher level of closure during unstable conditions and in the dominant wind directions. EC is widely recognized as a technique for approximating turbulent flow over uniform and level landscapes in stable atmospheric conditions (Baldocchi, 2020). Yet, the absence of surface energy equilibrium within the EC approach has been a reported by several researchers (Kutikoff *et al.,* 2019).

Gas emissions

Micrometeorological methods for measuring greenhouse and other gases have been widely utilized, for analyzing gases like CO_2, CH_4, N_2O and NH_3 from both point and non-point sources. These approaches offer distinct advantages due to their genuine in-situ nature. Unlike passive and dynamic chambers, these techniques can encompass larger areas, integrating fluxes effectively. Nevertheless, micrometeorological approaches carry their own specific limitations, contingent on assumptions about airflow uniformity and homogeneity (Hu *et al.,* 2014). The analysis revealed that there are five main micrometeorological methods for analyzing gases. This includes eddy covariance, inverse dispersion (Ro *et al.,* 2013), integrated horizontal flux (Brown *et al.,* 2002), micrometeorological mass difference (Harper *et al.,* 2011), tracer ratio (McGinn, 2006). Apart from this some other less popular methods listed in literature includes flux gradient, relaxed eddy accumulation, aerodynamic profile technique and the BREB method. These are usually used in combination with the main methods listed above. Kim *et al.,* (2005) quantified CH_4 emissions from paddy fields by measuring concentrations gradients from two different heights and turbulent exchange coefficient from the measured momentum fluxes by EC method. The gradient method is based on the assumption that the mechanism governing the turbulent transport is indiscriminant among scalar quantities. Harazono *et al.,* (2009) utilized micrometeorological measurements employing the EC method to assess CO_2 and H_2O fluxes originating from rice fields. The collected CO_2 measurements were employed to determine the net ecosystem exchange, which was subsequently disaggregated into gross primary productivity and ecosystem respiration through the utilization of measured micrometeorological data including PAR and air temperature. Turner *et al.,* (2010) employed a combination of the mass balance micrometeorological approach and the backward Lagrangian stochastic model to quantify NH_3 flux within a wheat field. Their results indicated that the latter technique subsequently offered more precise assessments of NH3 loss, irrespective of atmospheric stability conditions. Denmead *et al.,* (2010) employed the flux-gradient technique to quantify the release of CH_4 and N_2O gases from sugarcane fields. They achieved this by analyzing aerodynamic characteristics, atmospheric stability, and variations in mean gas densities at different heights above the sugarcane crop. The flux gradient method was also applied in a recent study by Machado *et al.,* (2020) for analyzing N_2O flux from maize fields to understand the response of combined use of nitrification and urease inhibitors. Meade *et al.,* (2011) quantified NH_3 emissions resulting from the application of high and low nitrogen pig manures on the surface in a field setting. This was accomplished using the micrometeorological mass balance approach, employing passive flux samplers positioned on a wind vane according to the prescribed method. Salazar *et al.,* (2012) also followed exactly same method for quantifying NH_3 emissions resulting from urea application to permanent pasture on a volcanic soil. Turner *et al.,* (2012) also applied this mass balance approach for quantifying ammonia volatilization from nitrogen fertilizers applied to cereals. Drawing upon consistent NH_3 concentration measurements at two different altitudes and various meteorological parameters collected via an EC system, Huo *et al.,* (2015) applied an inverse dispersion technique to estimate the varied NH_3 emissions occurring in winter wheat. Sommer and Misserblook (2016) compared the wind tunnel with integrated horizontal flux, (IHF) method for estimating NH_3 emissions from soil-slurry layer and reported comparable accuracies, however the micrometeorological methods perform well in rainy periods as compared to the tunnel method. Recio *et al.,* (2018) also used IHF to measure ammonia emissions from passive flus samplers mounted un a mast at five different heights to analyze the impacts nitrification inhibitors in maize. Tenuta *et al.,* (2019) measured N_2O flux emission using the micrometeorological flux gradient technique in fields of annual and perennial agricultural crops. The turbulent transfer coefficient was measured from similarity theory for momentum and sensible heat measured by sonic anemometer-thermometers. N_2O emissions were also integrated with CO_2 flux measurements, nitrogen fertilizer production, and potential uses of the end products to calculate the overall greenhouse gas balance.

Modelling and crop monitoring

Micrometeorological measurements play a crucial role in furnishing vital input data to a range of crop and soil models, enhancing their accuracy and applicability. By analyzing localized atmospheric conditions such as temperature, humidity, wind speed, and solar radiation at a finer scale, micrometeorology provides critical inputs for these models which aids in optimizing agricultural practices such as irrigation and nutrient application, mitigating weather-related risks, and achieving higher crop yields through informed decision-making based on microclimatic variations.

Initially researchers used several computers based models that utilizes micrometeorological parameters of crops for simulating yields, for example SBELTS for modelling soybean yield under tree shelter (Qi *et al.,* 2001), LAPS for land surface temperature (Mihailovic *et al.,* 2010), IVINE for vineyard physiological parameters (Andreoli *et al.,* 2019) etc. Models such as APSIM (Agricultural Production Systems sIMulator) and DSSAT (Decision Support System for Agrotechnology Transfer) heavily rely on micrometeorological data like temperature, humidity, solar radiation, and wind speed to simulate crop growth, yield, and soil processes more accurately (Smith *et al.,* 2019; Ran *et al.,* 2020; Wu *et al.,* 2021).

Mihailovic´ *et al.,* (2002) utilized land–air parameterization scheme (LAPS) for simulating air temperature within a sunflower canopy. Calculated temperatures aligned well with observations from thermographs, attributed to accurately parameterized aerodynamic resistances, particularly for canopy leaves and soil-canopy interaction. They reported proper partitioning of available energy for sensible and latent heat flux in the surface budget equation within the scheme. Luo and Goudriaan, (2004) illustrated that the MICROWEATHER model, which relies on the Penman-Monteith combined equation for assessing the surface energy balance, can be employed to simulate the occurrence of dew on rice plants. This can be achieved by utilizing average daily diurnal patterns of global radiation, net radiation, air temperature, vapor pressure, vapor pressure deficit, wind speed and humidity over the course of the season. van Dijk *et al.,* (2004) studied the micrometeorological parameters of intercropped maize and cassava to estimate the annual water use. The temperature fluctuation technique was employed by them, using quick-response thermocouples to measure variations in wet-bulb and dry-bulb temperatures, for calculating the Bowen ratio. Notably, when compared to direct computations, the use of Bowen ratios resulted in a notable 24% rise in sensible heat fluxes. However, latent heat fluxes inferred from both methods displayed a close agreement of within 10%. This discrepancy was primarily attributed to the more pronounced impact of high-frequency losses on directly computed fluxes. Additionally, simulations conducted with a soil–vegetation–atmosphere transfer model confirmed that modeled evaporation rates were consistent with measurements of soil hydrology. An interesting study by Aylor (2005) quantified pollen movement in maize canopy using combination of measurements, including micrometeorological measurements in crop canopy, and Lagrangian stochastic simulation model. They reported that within the canopy pollen fluxes at silk height exhibited considerable fluctuations because of high wind velocities and turbulence present in the upper canopy. The study highlighted the significant role that rebound and re-entrainment processes play in determining the quantity of maize pollen that reaches the silk. Mukherjee and Sarkar (2008) presented an indirect technique to approximate methane emissions from paddy fields and wetlands using a micrometeorological model, which was based on utilizing an analytical solution of the vertical diffusion-based Eulerian advection-diffusion equation. The model utilized derived parameters like Richardson Number and Monine-Obukhov length computed using direct measurements from a meteorological tower.

Kuwagata *et al.,* (2008) formulated a model to evaluate the temperature of water in paddy fields. This model was developed using heat balance equations applied to the water surface, and it also accounted for the impact of the plant canopy on temperature. The initial step involved calculating the average daily temperature of a water surface without vegetation, utilizing meteorological data such as air temperature, wind speed, specific humidity, solar radiation, and downward longwave radiation through heat balance equations. Subsequently, the daily average water temperature within a rice paddy was determined by introducing an adjustment term derived from the temperature of the non-vegetated water surface. This adjustment term was influenced by various factors including LAI (leaf area index), solar radiation, and wind speed. Yoshimoto *et al.,* (2011) developed an integrated micrometeorological model (IM^2PACT) for studying the panicle and canopy temperatures of rice using weather data under changing climate scenario. Kichah *et al.,* (2011) validated a computational fluid dynamics model for latent and sensible heat transfers occurring at plant level considering leaf temperature and aerodynamic resistances. The greenhouse micrometeorology was studied using set of sensors like sonic anemometer, thermocouples, humidity and temperature probes, pyrometers, pyrradiometers etc. The model was able to replicate both the absorbed radiation and the transpiration rate. Irmak *et al.,* (2013) examined a generalized nonlinear and linear modeling approaches for estimating canopy resistance using micrometeorological and plant factors in soybean canopies across various climatic zones in Nebraska, USA. They presented eight different one step models incorporating net radiation, relative humidity, wind speed, air temperature, vapor pressure deficit, leaf area index, aerodynamic resistance, and solar zenith angle to predict hourly canopy resistance. The consistency of the developed models was promising for the broader adoption of a simplified approach for crop evapotranspiration estimation, employing the Penman–Monteith model.

Molina-Herrera *et al.,* (2016) used the biogeochemical LandscapeDNDC model to explore different agricultural practices for their capacity to mitigate soil N_2O emissions and NO_3 leaching. The model utilized both crop and soil micrometeorological data in order to work effectively, which were obtained using the European flux database cluster. Consoli *et al.,* (2016) utilized CRITERIA model by changing ET rates, which were estimated using a satellite-based method and the Penman-Monteith equation for reference rates. Direct measurements were taken using the EC technique and sap flow heat pulse method for transpiration. Model results, focusing on soil moisture, were cross-validated with measurements of volumetric soil water content from time domain reflectometry probes. The study demonstrated the CRITERIA model's capability to accurately replicate the soil moisture distribution at the research site. The satellite-based approach offered dependable estimations of crop evapotranspiration, indicating the importance of remote sensing techniques in supporting agricultural water management. Boulard *et al.,* (2017) developed a computational fluid dynamics model to predict the distribution of temperature, water vapor and CO_2 in a semi-closed glass greenhouse. The model incorporated factors like sensible and latent heat fluxes, radiation and photosynthesis parameters of the crop. Comparisons between simulated and measured values showed a good agreement for temperature, humidity and CO_2 concentrations inside the green house, which shows the capability of such models to perform realistic simulations of inside climate distribution of closed systems. Andreoli *et al.,* (2019) used the IVINE crop growth model to simulate grapevine phenology and physiological functions. The model relied on a specific set of meteorological and soil data as essential inputs to define its boundaries and accurately depict environmental interactions. The air temperature and soil water potential were reported to be highly important parameters using the sensitivity analysis. Jiang *et al.,* (2020) studied the impacts of mist spray on micrometeorology of rice field. The findings indicated that the application of mist spray rapidly lowered temperatures and raised relative humidity within the canopy. This cooling impact was most pronounced at the canopy's uppermost portion, with its intensity diminishing progressively downward. Furthermore, mist spray contributed to an elevation in latent heat flux while causing a reduction in sensible heat flux within the rice field. Yoshimoto *et al.,* (2022) utilized Micrometeorological Instrument for Near Canopy Environment of Rice (MINCER) units installed in rice field to measure crop micrometeorological parameters including air temperature and the relative humidity for reducing the uncertainties in prediction of heat-induced spikelet sterility (HISS) in rice. They validated the reliability of employing panicle temperature as an indicator for predicting the susceptibility of crops to HISS under climate change. Additionally, by employing IM^2PACT to assess panicle temperature sensitivity, insights into the significance of precise relative humidity and air temperature measurements in forecasting HISS were provided.

CONCLUSIONS

Although micrometeorology in agriculture has been garnering more research focus, there exists a dearth of bibliometric analyses that quantitatively examine the literature and offer a comprehensive overview of the present research landscape. The outcomes of the results can lead to several conclusions. Despite the growing focus on crop micrometeorology in research, there is a noticeable absence of bibliometric analyses that quantitatively assess the literature and offer a bird's eye view on the recent research status. The outcomes of this work showed that there is no significant growth in number of works published on crop micrometeorology around the globe. The USA is the leading country in research of crop micrometeorology with maximum number of publications, while India hold the 10^{th} position. Micrometeorology, evapotranspiration, eddy covariance, energy balance and remote sensing are top 5 keywords cited are keywords in this field. Evapotranspiration, energy balance, gas emissions and modelling crop parameters with micrometeorological data are the key areas where majority of the researchers were focused. Future research could adopt a broader strategy when examining sources like Web of Science, ScienceDirect, IEEE, or PsycINFO to gain a more comprehensive perspective on applying crop micrometeorology. While the current analysis provides an extensive view of the research area, it lacks the depth that more focused approaches like systematic reviews or meta-analyses could offer. Nevertheless, this study provides valuable insights for researchers in the field, who can address these limitations in future work and explore the suggested agendas.

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