International Journal of Environment, Agriculture and Biotechnology
Vol-11, Issue-4; Jul-Aug, 2026
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Influence of Abiotic Factors on Soil Physico-Chemical and Biological Properties in LTFE

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Received: 13 Jun 2026; Received in revised form: 11 Jul 2026; Accepted: 16 Jul 2026; Available online: 22 Jul 2026

***Abstract*— The current research, " Influence of Abiotic Factors on Soil Physico-Chemical and Biological Properties in Maize Crop (Zea mays L.)" was carried out at the Instructional farm, Rajasthan College of Agriculture, Udaipur, Rajasthan during Kharif, 2025.Tweleve treatments with four replications were included in the randomized block design of the field study.The present study evaluated the influence of abiotic factors on soil physico-chemical and biological properties in maize under a long-term fertilizer experiment. Correlation analysis revealed that weather parameters influenced soil properties under the long-term fertilizer experiment in maize. Among the abiotic factors, rainfall had the greatest impact, showing positive associations with soil porosity, organic carbon, available nutrients, microbial populations, and enzyme activities, while negatively affecting bulk and particle density. Significant positive correlations were observed between rainfall and available phosphorus (r = 0.588*) and dehydrogenase activity (r = 0.549*). In contrast, minimum temperature exhibited negative relationships with soil organic carbon, available zinc, microbial populations, and enzyme activities. Overall, the findings indicate that rainfall is a key driver of soil fertility and biological activity, emphasizing the importance of adequate moisture for maintaining soil health and productivity in maize.*

***Keywords*— Abiotic factors, rainfall, soil health, microbial activity, dehydrogenase activity, nutrient availability, long-term fertilizer experiment, maize.**

I. INTRODUCTION

Maize (*Zea mays* L.), a member of the family *Poaceae*, originated in Mexico and Central America and is widely known as the "Queen of Cereals" because of its diverse uses and high productivity. The term *maize* is derived from the Taino word *mahiz*, later adopted into Spanish as *maiz* and incorporated into the botanical nomenclature by Linnaeus (Oxford Dictionary, 2015). Maize possesses a chromosome number of 2n = 20, a genome size of approximately 2.3 Gb, and more than 32,000 genes (Schnable *et al*., 2009). Its successful adaptation to diverse climatic conditions facilitated its global spread over centuries (Bouchet *et al*., 2013; Swarts *et al*., 2017). Globally, maize is the third most widely cultivated cereal crop and is extensively grown in arid and semi-arid regions (Shahzad *et al*., 2017). The crop performs optimally at temperatures ranging from 28–32 °C (Sánchez *et al*., 2017); however, its productivity is highly sensitive to climatic stresses, particularly heat and drought (Lobell *et al*., 2011; Schlenker & Roberts, 2009; Tebaldi & Lobell, 2018; Zhao *et al*., 2024). Temperatures exceeding 32 °C can reduce photosynthetic efficiency, increase transpiration, and impair pollen viability during anthesis, leading to yield losses (Crafts-Brandner & Salvucci, 2002; Gourdji *et al*., 2013). Likewise, drought stress during reproductive stages adversely affects photosynthesis, nutrient translocation, and grain development, with combined heat and water stress exerting particularly severe impacts on crop performance (Barnabas *et al*., 2008; Lobell *et al*., 2013; Zipper *et al*., 2016; Iizumi & Ramankutty, 2016; Lesk *et al*., 2016; Zampieri *et al*., 2019). Maize occupies about 197 million hectares worldwide (FAOSTAT, 2022). In India, it is cultivated on approximately 10.04 million hectares with a production of 33.62 million tonnes and an average productivity of 3349 kg ha^{-1} (DAC & FW, 2022). The crop contributes significantly to food, feed, and industrial sectors and is predominantly grown during the Kharif season, accounting for nearly 75% of total production (Murdia *et al*., 2016). Major maize-producing states include Andhra Pradesh, Karnataka, Rajasthan, Maharashtra, Bihar, Uttar Pradesh, and Madhya Pradesh. In Rajasthan, maize is mainly cultivated under rainfed conditions across the Mewar, Wagad, and Hadoti regions, covering about 0.95 million hectares with a production of 2.08 million tonnes (Commissionerate of Agriculture, Rajasthan, 2021–22). Maize plays a crucial role in global food and nutritional security, providing nearly 15% of global protein intake and 20% of calorie consumption. As a C_4 crop, it possesses high yield potential but requires substantial nutrient inputs for optimum growth and productivity (Adhikari *et al*., 2021). The grain contains about 72% starch, 10% protein, and 4% fat, along with essential vitamins and minerals (Ranum *et al*., 2014). Its utilization spans human food, poultry and livestock feed, industrial products, and bio-based industries (Parihar *et al*., 2011). Given its high nutrient demand and sensitivity to environmental stresses, efficient nutrient management remains essential for sustaining productivity and narrowing yield gaps under changing climatic conditions (Ghosh *et al*., 2020; Nduwimana *et al*., 2020).

II. MATERIAL AND METHODS

The study was conducted during *Kharif* 2025 at the fixed experimental site of the All India Coordinated Research Project on Long-Term Fertilizer Experiments (AICRP-LTFE) at the B_2 Instructional Farm, Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan, India. The investigation formed part of the 28th maize–wheat cropping sequence of the long-term experiment initiated in 1997. The site is located at 24°35′ N latitude and 73°42′ E longitude, at an altitude of 582.2 m above mean sea level, and falls under Agro-climatic Zone IVa (Sub-Humid Southern Plain and Aravalli Hills) of Rajasthan. Weather data were collected from the Agrometeorological Observatory, Rajasthan College of Agriculture, Udaipur. The recorded parameters included maximum and minimum temperature, morning and evening relative humidity ($RH_1$and RH_2), rainfall, sunshine hours, and evaporation. Mean weekly values were used for correlation analysis with soil properties. During the crop season, mean weekly maximum and minimum temperatures were 31.9°C and 25.1°C, respectively. Relative humidity ranged from 58.7–92.1% (RH_1) and 37.7–80.9% (RH_2), while total rainfall received was 682.7 mm. The experiment consisted of 12 treatments arranged in a Randomized Block Design (RBD) with four replications. The maize variety PHM-3, a high-yielding cultivar, was used for the study. Treatments were imposed as per the treatment schedule presented in Table 1. The recommended fertilizer dose for maize was 120 kg N, 26 kg P_2O_5, 25 kg K_2O, 5 kg Zn, and 40 kg S ha^{-1}. Phosphorus, potassium, zinc, and sulfur were applied as basal doses at the time of sowing. Nitrogen was applied in split doses, with half of the recommended amount applied as a basal dose and the remaining half top-dressed in two equal splits at critical growth stages of the crop. Data obtained from the experiment were subjected to statistical analysis using standard procedures, and analysis of variance (ANOVA) was performed to assess the effects of different treatments on the studied parameters. Weather parameters including maximum and minimum temperature, morning and evening relative humidity (RH_1 and 2), rainfall, sunshine hours, and evaporation were recorded during the crop season and their mean values were used for analysis. Soil samples collected at harvest were analyzed for physical properties (bulk density, particle density, and porosity), chemical properties (pH, EC, organic carbon, available N, P, K, and Zn), and biological properties (bacterial, fungal, and actinomycetes populations, dehydrogenase activity, and alkaline phosphatase activity). The relationships between weather parameters and soil properties were assessed using Pearson's correlation analysis, and the significance of correlation coefficients was tested at the 5% probability level ($P \leq 0.05$).

Table 1: Treatment Details

Treatment No.	Treatment Details
T_1	100% NPK
T_2	100% NPK + Zn
T_3	100% NPK + Zn + S
T_4	100% NPK + S
T_5	100% NPK + Bio
T_6	FYM 10t ha^{-1} + (100% NPK -NPK of FYM
T_7	100% NPK + FYM 10t ha^{-1}
T_8	FYM 20t ha^{-1}
T_9	150% NPK
T_{10}	100% NP

T_{11}	100% N
T_{12}	Control

III. RESULT AND DISCUSSION

❖ Influence of Abiotic Factors on Soil Physico-Chemical Properties

The correlation analysis between average weather parameters and soil physico-chemical properties under the long-term fertilizer experiment revealed that rainfall exerted the greatest influence on soil characteristics (Table 2). Rainfall exhibited negative correlations with bulk density (r = -0.518) and particle density (r = -0.586), while showing positive associations with porosity (r = 0.452), soil organic carbon (r = 0.526), available nitrogen (r = 0.518), available phosphorus (r = 0.588*), available potassium (r = 0.395), and available zinc (r = 0.247). The significant positive correlation between rainfall and available phosphorus indicated enhanced phosphorus availability under favorable soil moisture conditions. Maximum temperature showed weak positive correlations with bulk density, particle density, electrical conductivity, and available nutrients, whereas it was negatively associated with porosity, organic carbon, and available zinc. Minimum temperature exhibited positive relationships with bulk density, particle density, soil pH, and electrical conductivity, but was negatively correlated with porosity, organic carbon, available potassium, and available zinc. The strongest negative association of minimum temperature was observed with available zinc (r = -0.512) and organic carbon (r = -0.480). Morning relative humidity (RH_1) showed positive correlations with soil pH, electrical conductivity, available nitrogen, phosphorus, and zinc, whereas RH_2 displayed positive associations with porosity and available nutrients. Sunshine hours had generally weak correlations with most soil properties. Evaporation showed negative correlations with soil pH (r = -0.590), electrical conductivity (r = -0.688), available nitrogen (r = -0.174), phosphorus (r = -0.186), and potassium (r = -0.107), indicating the adverse effect of moisture loss on soil fertility parameters. Similar findings were also observed by Rajkhowa (2017), Xia *et al.* (2021), Yadav *et al.* (2021), Hu *et al.* (2024) and Manea *et al.* (2024).

Table 2: Correlation coefficients between average weather parameters and soil physiochemical properties of maize under long term fertilizer experiment

Weather parameters	Physical Properties			Chemical Properties						
	BD	PD	Porosity (%)	PH	EC	OC (%)	Available N (kg ha^{-1})	AvailableP (kg ha^{-1})	Available K (kg ha^{-1})	Available Zn (mg kg^{-1})
Max Temp. (°C)	0.060	0.152	-0.023	0.005	0.313	-0.155	0.171	0.296	0.101	-0.345
Min Temp. (°C)	0.357	0.304	-0.345	0.232	0.340	-0.480	-0.017	0.089	-0.123	-0.512
RH_1(%)	0.013	-0.165	-0.075	0.462	0.303	-0.053	0.133	0.363	-0.002	0.127
RH_2 (%)	-0.078	0.123	0.145	0.012	0.356	0.001	0.264	0.268	0.228	-0.202
Rainfall (mm)	-0.518	-0.586	0.452	0.311	0.326	0.526	0.518	0.588*	0.395	0.247
Sunshine (hrs)	-0.064	-0.054	0.069	0.224	0.352	0.039	0.151	0.012	0.174	-0.025
Evaporation (mm)	-0.033	-0.140	-0.021	-0.590	-0.688	0.037	-0.174	-0.186	-0.107	-0.078

Table 3: Correlation coefficients between average weather parameters and soil biological properties at harvest under long term fertilizer experiment

Weather parameters	Soil microbial population (cfu g^{-1})			Dehydrogenase activity (µg TPF g^{-1} 24 h^{-1} soil)	Alkaline phosphatase activity (µg PNP g^{-1}soil h^{-1})
	Bacteria (10^6)	Fungi (10^4)	Actinomycetes (10^5)		
Max Temperature (°C)	-0.116	-0.120	-0.159	-0.058	-0.123
Min Temperature (°C)	-0.391	-0.449	-0.438	-0.375	-0.421
RH_1(%)	-0.081	-0.022	0.015	0.002	0.029
RH_2 (%)	-0.038	0.022	-0.071	0.049	0.058
Rainfall (mm)	0.501	0.460	0.521	0.549*	0.435
Sunshine (hrs)	-0.020	0.029	-0.017	0.004	0.058
Evaporation (mm)	0.044	0.128	0.093	0.031	0.061

❖ Influence of Abiotic Factors on Soil Biological Properties

Weather parameters also influenced soil biological properties and microbial activity (Table 3). Among all abiotic factors, rainfall demonstrated the strongest positive association with soil biological attributes. It was positively correlated with bacterial population (r = 0.501), fungal population (r = 0.460), actinomycetes population (r = 0.521), dehydrogenase activity (r = 0.549*), and alkaline phosphatase activity (r = 0.435). The significant positive correlation between rainfall and dehydrogenase activity indicated enhanced microbial activity and biological functioning under adequate moisture availability. Maximum temperature exhibited weak negative correlations with microbial populations and enzyme activities. Similarly, minimum temperature showed comparatively stronger negative associations with bacteria (r = -0.391), fungi (r = -0.449), actinomycetes (r = -0.438), dehydrogenase activity (r = -0.375), and alkaline phosphatase activity (r = -0.421), suggesting that elevated temperatures may suppress soil microbial growth and enzymatic processes. Relative humidity (RH_1 and RH_2) showed weak and inconsistent relationships with soil biological parameters. Sunshine hours exhibited negligible correlations with microbial populations and enzyme activities. Evaporation was positively but weakly associated with biological properties, indicating a limited influence on soil microbial activity. Similar findings were also observed by Tian *et al.* (2016), Bairwa *et al.* (2021) and Qiqige *et al.* (2023).

IV. CONCLUSION

The correlation analysis demonstrated that abiotic factors influenced the soil physico-chemical and biological properties of maize under the long-term fertilizer experiment, with rainfall emerging as the most important weather parameter. Rainfall showed positive associations with soil porosity, organic carbon, available nutrients, microbial populations, and enzyme activities, while exhibiting negative relationships with bulk density and particle density. Significant positive correlations of rainfall with available phosphorus (r = 0.588*) and dehydrogenase activity (r = 0.549*) indicated that adequate moisture availability enhances nutrient availability and microbial activity in soil. In contrast, minimum temperature generally exhibited negative relationships with soil organic carbon, available zinc, microbial populations, and enzymatic activities, suggesting adverse effects of elevated temperatures on soil fertility and biological functioning. Other weather parameters, including relative humidity, sunshine hours, and evaporation, showed comparatively weak and non-significant associations with most soil properties. Overall, the study highlights the pivotal role of rainfall in regulating soil nutrient dynamics and biological activity, emphasizing the importance of favorable moisture conditions and climate-resilient nutrient management strategies for sustaining soil health and productivity in maize-based cropping systems.

ACKNOWLEDGEMENT

The authors sincerely acknowledge the support, facilities, and infrastructure provided by Rajasthan College of Agriculture, MPUAT, Udaipur, which enabled the successful completion of this research. The authors also express their heartfelt gratitude to the faculty members and staff of the Department of Soil Science and Agricultural Chemistry for their continuous guidance, encouragement, and valuable assistance throughout the course of the study.

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