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MICROCLIMATE, GROWTH, PHYSIOLOGY AND PRODUCTIVITY OF WHEAT UNDER AGROFORESTRY VERSUS AGRICULTURE PLOT IN SEMI-ARID REGION OF PUNJAB, PAKISTAN

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Abstract

Microclimate, wheat growth and productivity were evaluated in agriculture (AP) and agroforestry plot (AFP). Results showed the difference of air temperature (3.83°C), relative humidity (6.6%), soil temperature (2.3°C), and moisture (5%) between AP and AFP. Similarly, tiller height (114.9 cm), spike length (12.1 cm), number of tillers m^{-2} (413), grain weight m^{-2} (364.6 g) and 1000 grain weight (50.2 g) were found significantly high at 12.5 ft from tree stem in AFP as compared to AP. CO_2 assimilation rate (15.4 μmol m^{-2} s^{-1}), stomatal conductance (0.41 mmol mol m^{-2} s^{-1}) and transpiration rate (4.3 mmol mol m^{-2} s^{-1}) was also found highest in wheat at 12.5ft as compared to AP. Overall, wheat productivity remained similar in AFP as compared to AP. Therefore, it can be concluded that AFP can ameliorate in microclimate and productivity under changing climate.

Introduction

Change in climate is happening very fast and posing a serious threat to agricultural productivity due to erratic precipitation patterns, temperature fluctuations, severe floods, and droughts (Abbass *et al*. 2022). Recent reports concluded that rise in CO_2 emissions, increase in global temperatures and fluctuating precipitation patterns is reducing agriculture productivity (IPCC 2021). Reports have been revealed that 923.7 million peoples were found severely food insecure despite global efforts on achieving zero hunger target and decreasing the impacts of climate change (Dissanayaka *et al*. 2024). Therefore, climate change vulnerabilities have become a major concern over the recent decade, especially in arid to semi-arid region around the globe (Fahad *et al*. 2022).

Worldwide various agroforestry systems being considered to cope with the climate change scenario, and for the stability of agriculture (Barman *et al*. 2025). Studies have shown agroforestry as an alternative land use strategy to reduce climatic impacts, sustain crop productivity, reduce poverty and ensure food security. Agroforestry, a sustainable approach that involves the intentional integration of a various tree species with farm crops, which can help limits the use of agrochemicals, enhance and accelerates mineralization and rectify the soil problems (Santiago-Freijanes *et al*. 2021). Therefore, promoting agroforestry can be the best way to mitigate global warming by capturing CO_2, and O_2 liberation (Xue *et al*. 2021), Moreover, tree provide other benefits like microclimate moderation and water retention by tree canopies reduces evapotranspiration and extends the duration of water infiltration.

In agroforestry, two main system are prevalent, alley cropping and border cropping stem. Border cropping improves microclimate to a lesser extent as compared to other environmental hazards like strong wind (Panda 2025). Abbass *et al*. (2022) found that revenue generated by the agroforestry system is three times higher in comparison to conventional agricultural system. Furthermore, it was reported in a teak-based agroforestry system was found very efficient in controlling the effects in natural disasters (Roshetko *et al*. 2013).

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Recently, Pakistan has been declared as the most vulnerable county of South Asia due to unprecedented heat wave and flash floods resulting in immense losses in agriculture sector and economy during 2022 (Mishra *et al.* 2024). Although, agroforestry has long history in Pakistan; however, modern farmers are reluctant to adopt agroforestry due to the fear of productivities losses. In addition, some studies have also strengthened this point of view by demonstrating the loss of productivity under agroforestry system (Udumann *et al.* 2024). However, in the climate change scenario, agroforestry can be a solution but unfortunately studies quantifying the agroforestry services are rare in Pakistan, especially those related to microclimate and crop productivity. Therefore, the current study has been designed to characterize microclimate, growth and productivity of wheat crop in Pakistan, in agriculture and agroforestry system.

Materials and Methods

The experiment was conducted during the month of November 2023 to April 2024, at the Chak No. 250/JB, Painsra, Faisalabad, Punjab, Pakistan (Latitude 31°35′N, Longitude 72°80′E). Two plots were selected, agriculture plot (AP) and agroforestry plot (AFP), both having an area of 160 × 272 ft. The AP was without trees whereas, AFP was established in 2005 with trees planted at a plant-plant distance of 15 feet around the field boundaries. *Bombax ceiba* L. trees was planted along the field boundaries.

Both AP and AFP were ploughed and rotavated 2-3 times followed by planking. Wheat variety Akbar-2019 was acquired from Wheat Research Institute, Faisalabad, Pakistan. Seed sowing was completed on 15th November 2023 using drill showing method, at a seed rate of 40 kg acre^{-1}. Recommended dose of N-P-K fertilizers and 3 irrigations were applied. Twenty-four 1 m^2 quadrate were selected: 6 in AP; 6 at 2.5feet, 6 at 7.5feet, 6 at 12.5feet from tree stem in AFP. All data was taken in these preselected quadrates and overall productivity was measured at harvest.

In both the plots air temperature (METER group, USA) and soil moisture (SATO EK-2000MC; ART.46908) was recorded twice a week between 12 to 1 pm throughout the experiment. Data was used to calculate difference of air temperature (ΔT_a) and soil moisture (ΔM_s) between AP and AFP.

In both the AP and AFP, chlorophyll contents were measured on the preselected flag leaves using chlorophyll meter (atLEAF+, USA) between 12 to 12:30 pm. Leaf gas exchange measurements were also taken on the same leaf and CO_2 assimilation rate, stomatal conductance and transpiration rate and water use efficiency was measured between 12 to 1 pm under ambient conditions. Wheat was harvested on 29th April 2024 and data related to tiller height, spike length, number of tillers per m^2, total grain weight per m^2 and 1000 grain weight was measured, and total wheat grain and straw production was calculated in AP and AFP. Harvest index (HI) was calculated as HI = (GY/TY) × 100, where GY is grain yield and TY is total yield (grain + straw).

Data corresponding to ΔT_a, and ΔM_s was analyzed using one way ANOVA for date effect. Dunnett two-sided test was used for pair wise comparison of means. The data of wheat growth and productivity was analysed using one ANOVA for treatment effect (AP, 2.5, 7.5 and 12.5 feet in AFP). The difference between means was tested using Tukey's HSD test, and means were expressed with their standard error. All tests were conducted in STATISTICA, version 12.5 (Maison Alfort, France) and were considered significant at $P < 0.05$.

Results and Discussion

Throughout the growing season, especially from November 11, 2023, to March 21, 2024. the mean T_a was 24.4^{o}C in AP and 23.7^{o}C in AFP. During March 25 to April 15, 2024, mean T_a was recorded at 35.1^{o}C in AP and 31.3^{o}C in AFP. Mean ΔT_a during November 16, 2023, to March 21,

2024. However, after March 2024, mean ΔT_a was higher (3.83°C). Furthermore, post-hoc analysis showed that ΔT_a was found significant only during the early summer month (Figs 1 and 2). These findings are aligned with the studies of Dissanayaka *et al*. (2024) and Barman *et al*. (2025) who demonstrate that border plantations in agroforestry systems act as windbreaks and radiation filters, resulting in a more stable microclimate, conducive for rabi crops. Kumar *et al*. (2020) observed that tree canopy cover moderate temperature extremes and creates a more favourable microenvironment for understory crops especially during summer stress. This type of adaptive buffering mechanism is particularly relevant in the context of climate change, where rising temperatures are expected to intensify heat stress episodes for staple crops like wheat.

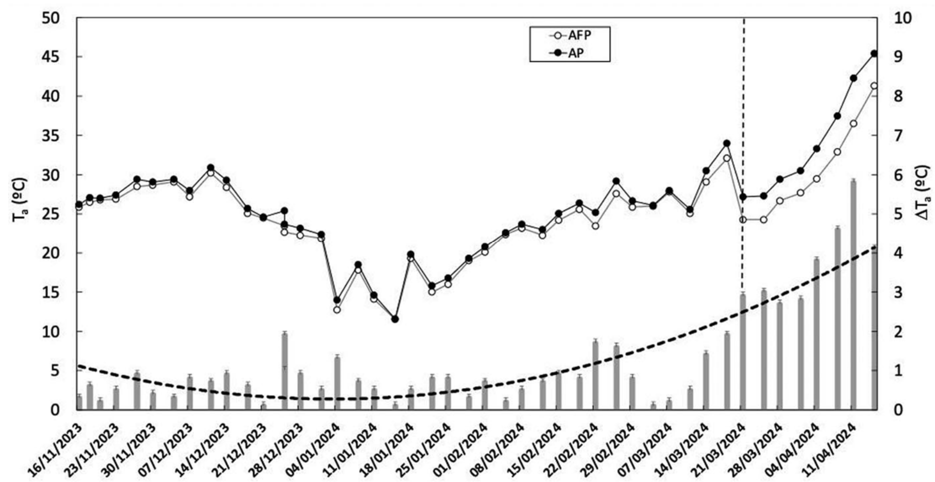

Fig.1. Mean air temperature (T_a) variations in agriculture plot (AP) and agroforestry system (AFP) throughout the duration of wheat. Bars represent the difference of air temperature between AP and AFP (ΔT_a).

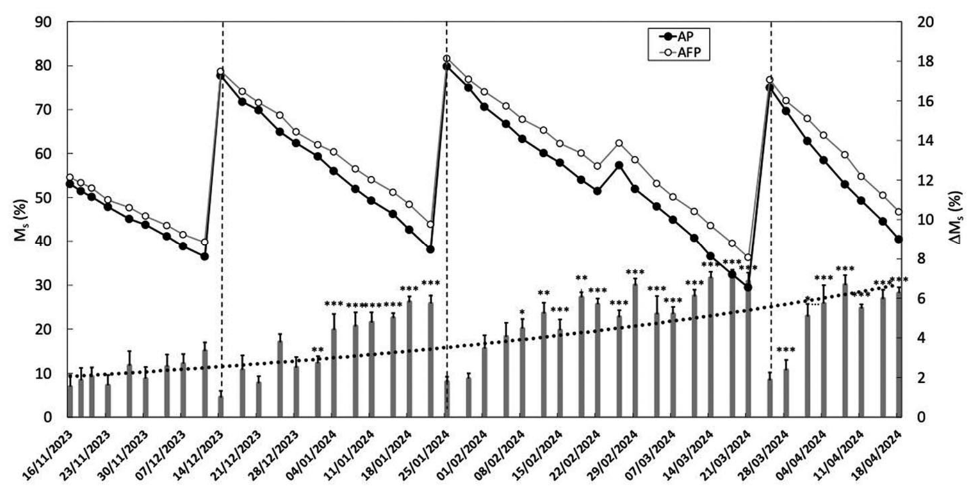

Fig. 2. Mean per cent soil moisture (M_s) variations under in agriculture plot (AP) and agroforestry system (AFP) throughout the duration of wheat production. Bars represent the difference of soil moisture between AP and AFP (ΔT_a).

After first irrigation M_s decreased from 77.68 to 38.1% in AP, and 78.7 to 43.8% in AFP. After the second irrigation, M_s decreased from 79.8 to 29.4% in AP, and 81.6 to 36.3% in AFP, after the third irrigation the decrease in AP was from 74.95 to 40.5%, and 76.8 to 46.7% in AFP. After first irrigation mean ΔM_s was found to be 3.7%, after second and third irrigation mean ΔM_s was higher, 5.07 and 4.9%, respectively (Fig 2). Post-hoc test showed that after each irrigation, rate of decrease in soil moisture contents was higher in AP as compared to AFP. Similar results have been reported by Fahad *et al*. (2022) and Panda (2025), who found that agroforestry systems improve soil water retention due to low air circulation, increased air humidity, reduce surface runoff, and enhance organic matter content in soils since all these factors contribute to higher water-holding capacity of soil. These findings are also consistent with the study of Arshad *et al*. (2024), who emphasized the role of agroforestry in stabilizing soil temperature fluctuations, thereby enhancing crop resilience under climate variability.

Table 1. Mean values of various wheat growth and physiological parameters in AP and AFP at different distance (ft) from stem.

Parameters	AP	AFP 12.5	AFP 7.5	AFP 2.5	T-effect
Tiller height (cm)	108.4 ± 1.38b	114.9 ± 0.59a	111.9 ± 0.68b	98.2 ± 1.69c	P<0.001
Spike length (cm)	11.6 ± 0.21b	12.1 ± 0.23a	11.8 ± 0.20b	10.1 ± 0.14c	P<0.001
No. of tiller m^{-2}	403 ± 4.69b	421 ± 3.47a	413 ± 7.70b	302 ± 5.53c	P<0.001
GW m^{-2} (g)	340.4 ± 3.9b	364.6 ± 4.7a	355.2 ± 4.4b	286.4 ± 1.52c	P<0.001
1000 GW (g)	48.1 ± 1.04b	50.2 ± 0.93a	49.8 ± 1.16b	39.1 ± 0.66c	P<0.001
SPAD	50.62 ± 0.33a	50.9 ± 0.37a	47.6 ± 0.28b	43.2 ± 0.61c	P<0.001
CO_2 assimilation rate	15.0 ± 0.05b	15.4 ± 0.04a	13.6 ± 0.10c	12.3 ± 0.05d	P<0.001
Stomatal conductance	0.31 ± 0.04b	0.41 ± 0.03a	0.26 ± 0.01c	0.22 ± 0.01d	P<0.001
Transpiration rate	3.36 ± 0.45b	4.3 ± 0.36a	3.14 ± 0.12c	2.6 ± 0.18d	P<0.001
Water use efficiency	5.58 ± 0.61a	4.02 ± 0.43b	5.6 ± 0.40a	4.07 ± 0.24b	P<0.001

Significant differences were found in tiller height (H_t), spike length (L_s), number of tillers m^{-2} (NoT) and 1000 grain weight across AP and AFP (Table 1). All the growth and productivity traits were found lowest in wheat growing at 2.5ft from tree stem in AFP and, highest in wheat growing at 12.5ft from tree stem in AFP as compared to AP. Chlorophyll content (Chl.c) varied significantly between AP and AFP and were found lowest in wheat growing at 2.5ft from tree stem (44.3) in AFP. Similarly, CO_2 assimilation rate, stomatal conductance and transpiration rate was found highest in wheat growing at 12.5 ft from tree stem in AFP (Table 1). In contrast, water use efficiency was found high in AP and AFP at 2.5 ft form tree stem while it was low at 7.5 ft and 2.5 ft from tree stem. Overall, total wheat grain and straw production in AP was low (1394 kg and 1374 kg, respectively), as compared to AFP (1425 kg and 1412 kg). These results corroborating with Santiago-Freijanes *et al.* (2021), who emphasized the positive influence of light quality on wheat stem elongation, internodal development and seed development. Udumann *et al*. (2024) documented the adverse effect of canopy-induced shading on chlorophyll synthesis in a similar way was aligned with the previous studies which demonstrated in a boundary plantation of *Dalbergia sissoo* with wheat and *Populus deltoides* with maize crop and found that CO_2 assimilation rate increased with distance from stem (Mishra *et al*. 2024, Sidhu 2025). The distance dependent response aligns with earlier reports of Sharma and Sah (2020) who highlighted that crop yield losses in agroforestry systems are minimised at wider tree-crop spacings. These findings are corroborated to Arshad *et al*. (2024), who illustrated that water use efficiency of crops improved under agroforestry systems along with microclimate regulations moreover, findings demonstrated increased wheat growth and productivity under AFP. In this study, HI was high in

AP and low in AFP. These dynamics support the assertion that agroforestry systems, when spatially optimized, can enhance wheat growth and production (Kumar *et al.* 2020). Similar physiological trade-offs have been documented by Yuan *et al.* (2021), who noted that under agroforestry systems thermal and evaporative stress was reduced, thereby supporting sustained growth under warming climates. Overall, the results highlight that agroforestry systems not only mitigate microclimatic extremes but also improve wheat resilience, particularly under late-season heat stress conditions. In the broader scenario of food security, such systems offer dual benefits: stabilizing crop yields and enhancing ecosystem services such as water conservation and soil temperature regulation. As climate change is projected to increase the frequency of heat waves and water scarcity (IPCC 2021), agroforestry emerges as a viable climate-smart strategy for sustaining wheat productivity in vulnerable regions, on wheat as a staple food. Thus, the integration of trees with annual cropping systems can be positioned as a sustainable pathway for both climate adaptation and food security. By moderating microclimates, conserving soil moisture, and supporting higher yield stability, agroforestry systems hold potential to counteract some of the most pressing challenges posed by climate change.

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