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Photosynthetic Performance of *Zea mays* integrated with *Neolamarckia cadamba* under climate change condition

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Abstract

Anthropogenic activities have increased CO_2 emissions, elevating global temperatures and disrupting rainfall patterns, thus affecting crop productivity. This study examines the photosynthetic performance of *Zea mays* under elevated temperatures (25˚C and 30˚C) and CO_2 levels (400 and 700 ppm) in two cropping systems: monoculture and an agroforestry system combining *Z. mays* with *Neolamarckia cadamba*. The experiment consisted of three water treatments: P1 (low rainfall), P2 (normal rainfall), and P3 (high rainfall), each with four replicates, giving a total of 12 pots per cropping system and 36 pots overall across the three experimental conditions. Key photosynthetic parameters measured were CO_2 assimilation rate (A), stomatal conductance (Gs), transpiration rate (E), and water use efficiency. Results revealed that *Z. mays* in the agroforestry system under normal rainfall, 25˚C, and 700 ppm CO_2 recorded the highest net assimilation rate. This is likely due to favorable microclimatic conditions provided by the tree canopy, including better moisture retention and reduced heat stress. In contrast, the lowest photosynthetic performance occurred under low rainfall (P1), higher temperature (30˚C), and ambient CO_2 concentration (400 ppm). Under these stress conditions, stomatal conductance declined significantly, restricting CO_2 uptake and reducing photosynthetic efficiency. These findings suggest that agroforestry systems could help mitigate the negative impacts of climate change on crop productivity. Integrating trees with crops could enhance photosynthetic performance under future climate scenarios, supporting sustainable agriculture and food security.

Plain Language Summary

Human activities have increased CO_2 levels and global temperatures, causing changes in rainfall and reducing water availability for crops. This study tested how

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Abbreviations: CRD, completely randomized design; PAR, photosynthetically active radiation; WUE, water use efficiency.

maize (*Zea mays*) responds to different temperatures (25˚C and 30˚C), CO_2 levels (400 and 700 ppm), and rainfall (low, normal, and high) in two setups: monoculture and with *Neolamarckia cadamba* (agroforestry). Results showed that maize grew best in the agroforestry system under normal rainfall, 25˚C, and high CO_2, likely due to better shade and soil moisture. In contrast, maize in monoculture under low rainfall, 30˚C, and low CO_2 performed poorly. These findings suggest that agroforestry can help crops cope with climate stress and support future food security.

1 | INTRODUCTION

Climate change has become a major driver of environmental change of environmental degradation, negatively impacting plant germination, growth and biodiversity. Over the past two decades, anthropogenic activities such as the burning of fossil fuels, deforestation, and industrialization have exacerbated these effects, leading to an increase in greenhouse gas emissions and global warming. According to the Intergovernmental Panel on Climate Change, global surface temperatures have continued to rise at an unprecedented rate, with increasing frequency and intensity of extreme weather events, posing significant risks to agricultural systems and food security worldwide (Slangen et al., 2022). Such climatic changes have profound effects on agriculture, such as changes in crop phenology, shortened growing seasons, soil degradation, and increased occurrence of extreme weather events (World Bank, 2005)

Increased atmospheric carbon dioxide (CO_2) concentrations, a hallmark of climate change, can influence plant physiological processes. While elevated CO_2 levels often stimulate photosynthesis, particularly in C_3 plants, the response in C_4 species such as *Zea mays* (maize) is more complex. *Z. mays* is a C_4 crop species, and its photosynthetic response to elevated atmospheric CO_2 differs from that of C_3 plants. While increased CO_2 can enhance photosynthesis by improving carbon fixation efficiency, responses in C_4 species such as maize are often limited and context-dependent (Abebe et al., 2016). Elevated CO_2 may temporarily increase photosynthetic rates, but this effect can be constrained by physiological acclimation, reduced stomatal conductance, and changes in leaf nitrogen content. Studies have shown that elevated CO_2 can increase the photosynthetic rates of maize by improving the efficiency of carbon fixation. However, this effect may be transient due to physiological acclimation and feedback mechanisms (Kirschbaum, 2011). In addition, increased CO_2 can lead to a reduction in stomatal conductance and leaf nitrogen content, potentially offsetting the initial gains in photosynthetic performance (Ainsworth & Rogers, 2007)

Temperature is another important factor that influences plant physiology. Elevated temperatures can affect enzyme activity, membrane stability, and general metabolic rates. For example, the activity of Rubisco activase, an enzyme important for carbon fixation, is sensitive to heat and can become a limiting factor under high temperatures (Yamori & von Caemmerer, 2009). In addition, elevated temperatures can disrupt the balance between photosynthesis and respiration, lowering net carbon gain and ultimately reducing crop yield (Heskel et al., 2014).

In the context of sustainable agriculture, the integration of agroforestry practices has been proposed as a strategy to mitigate the negative effects of climate change. *Neolamarckia cadamba* (Kelempayan), a fast-growing tropical tree species, has attracted attention for its potential role in agroforestry systems. Its integration with crops such as maize can improve soil fertility, enhance microclimatic conditions, and potentially influence the physiological performance of companion plants (Aman, 2006; Karyati et al., 2021). However, few studies have examined the interactions between *N. cadamba* and maize, particularly under varying CO_2 concentrations and temperature regimes.

This study evaluated the effects of temperature, CO_2 concentration, and rainfall on the photosynthetic performance of *Z. mays* grown in monoculture and in an agroforestry system with *N. cadamba*. By analyzing key physiological parameters such as net CO_2 assimilation rate, transpiration rate (E), stomatal conductance, and water use efficiency (WUE), the potential benefits and challenges of such agroforestry systems under changing climate conditions will be highlighted. The results will contribute to the development of climate-resilient agricultural practices that improve crop productivity and sustainability.

2 | MATERIALS AND METHODS

2.1 | Study area

The experiment was conducted in a shelter house at the Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, Kota Samarahan, Sarawak, Malaysia. Temperature and relative humidity inside the shelter house were not actively controlled but continuously monitored using a hygrometer, with recorded values ranging from 26˚C to 31˚C and 71% to 76%, respectively. *Neolamarckia cadamba* and *Z. mays* were grown in the shelter house to minimize pest infestation and to ensure uniform sunlight and water supply. The temperature range in the shelter was 26˚C–31˚C with a humidity of 71%–76%, which was determined using a hygrometer.

2.2 | Planting process

Seedlings of *N. cadamba* were obtained through tissue culture and transplanted into pots with a diameter of 0.4 m and a depth of 0.3 m. Topsoil and chicken manure were used as growth media in a volume ratio of 4:1. After the seedlings of *N. cadamba* had reached a height of 20–30 cm, the seeds of *Z. mays* were planted directly into the pots and planted simultaneously with *N. cadamba*. The experiment was arranged in a completely randomized design (CRD), with cropping system (monoculture and agroforestry) treated as an experimental factor rather than a blocking factor. The experiment consisted of three precipitation treatments, each replicated four times. The treatments are listed below:

1. Treatment 1: High precipitation × 4 replicates.
2. Treatment 2: Normal precipitation × 4 replicates.
3. Treatment 3: Low precipitation × 4 replicates.

In this experiment in the CRD, the factors include a division into three groups: *N. cadamba* and *Z. mays* as agroforestry, only *Z. mays* as a crop, and only *N. cadamba* as a tree.

2.3 | Photosynthetic performance measurement under temperature activation

For each treatment, photosynthetic measurements were conducted on three fully expanded leaves per pot. With four replicated pots per treatment, this resulted in a total of 12 leaf-level measurements for each treatment combination. This was done using a portable open-flow gas exchange system equipped with a 2 × 3 cm chamber and a light-emitting diode lamp as light source (LI-6400XT, LICOR). Photosynthetic light-response (A-Li) curves of the leaves were developed under a series of increasing values of photosynthetic photon flux density of 10, 40, 60, 120, 250, 500, 1000, 1500, and 1800 µmol (photons) m^{-2} s^{-1} and a maintained intercellular CO_2 concentration of 400 ppm in the chamber. The temperature of the leaf in the chamber was set to two values, either 25˚C or 30˚C, as the mean leaf temperature at the study sites ranged from 26.5˚C to 29.0˚C (Ibrahim et al., 2020). Net CO_2 assimilation rates (A; µmol CO_2 m m^{-2} s^{-1}), stomatal conductance (Gs; mol H_2O m^{-2} s^{-1}) and E(mmol H_2O m^{-2} s^{-1}) were determined directly from the portable gas exchange system, while WUE (µmol CO_2 mmol $(H_2O)^{-1}$) was calculated from the A/E ratio.

2.4 | Photosynthetic performance measurement under CO_2 activation

Photosynthetic performance under CO_2 activation was measured using the same gas exchange system and light-response protocol as described for temperature activation. Measurements were conducted at a constant leaf temperature of 25˚C, while intercellular CO_2 concentration was set at either 400 or 700 ppm. The intercellular CO_2 concentration was set to two values, either 400 or 700 ppm within the chamber (Ibrahim et al., 2020). Net CO_2 assimilation rates (A; µmol CO_2 m^{-2} s^{-1}), stomatal conductance (Gs; mol H_2O m^{-2} s^{-1}) and E (mmol H_2O m^{-2} s^{-1}) were determined directly from the portable gas exchange system, while WUE (µmol CO_2 mmol $(H_2O)^{-1}$) was calculated from the A/E ratio.

2.5 | Statistical analysis

A three-way analysis of variance was used to assess the interactions between water precipitation and temperature or internal CO_2 concentration on the variables of instantaneous gas exchange efficiencies (net CO_2 assimilation rate [A], transpiration rate [E], stomatal conductance [Gs], and WUE). Significant differences were then further analyzed using Tukey tests. An unpaired *t*-test was used to analyze significant differences between temperatures (25˚C and 30˚C) and internal CO_2 concentrations (400 and 700 ppm). For each treatment, measurements were based on four replicated pots, with three leaves sampled per pot. Thus, statistical analyses were conducted using pot-level means ($n = 4$ per treatment). All statistical analyses were performed using the Statistical Analysis System version 9.2.

3 | RESULTS

3.1 | Photosynthetic assimilation response under different temperatures and agroforestry system

The photosynthetic light-response curves revealed clear effects of precipitation and temperature on net CO_2 assimilation in both species. *Zea mays* exhibited higher photosynthetic performance at 25˚C than at 30˚C, particularly under normal and high precipitation (P3). Low rainfall combined with elevated temperature consistently reduced assimilation rates,

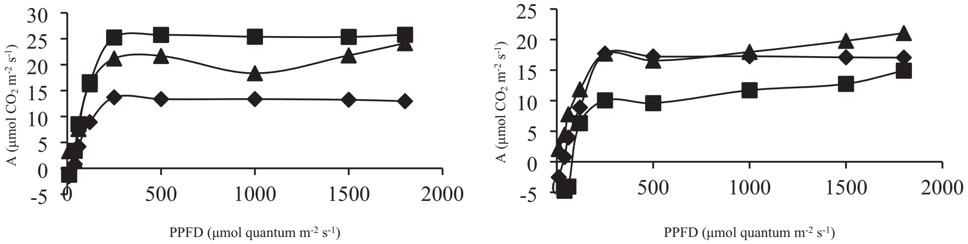

FIGURE 1 Photosynthetic light response (A-Li) curves of only *Zea mays* (only crop) under three precipitation patterns, P1: Low precipitation, P2: Normal precipitation, and P3: High precipitation, measured at a constant intercellular CO_2 concentration of 400 ppm and leaf temperature of either 25˚C or 30˚C. Symbols for square represent P1: low precipitation, and pyramid represents P2: normal precipitation and diamond represents P3: high precipitation. PPFD, photosynthetic photon flux density.

especially at low light levels. In contrast, agroforestry conditions moderated these stress effects, resulting in higher assimilation under favorable moisture conditions. Detailed numerical values are presented in the corresponding figures.

Figure 1 illustrates that the photosynthetic light-response (A–Li) curves of *Z. mays* varied markedly with precipitation and temperature. At 25˚C, low precipitation (P1) constrained photosynthesis under low light, indicating strong light limitation under drought stress, whereas normal and P3 supported higher assimilation. Under moderate to high light, P1 and P3 generally achieved higher assimilation than normal precipitation (P2). At 30˚C, drought stress effects were amplified, with P1 showing negative assimilation at low light. Across light levels, P3 consistently supported higher photosynthetic performance than P2, particularly under elevated temperature, while P2 tended to plateau at high irradiance.

Figure 2 shows that *Z. mays* showed a higher overall photosynthetic performance at a moderate temperature of 25˚C compared to 30˚C in all precipitation treatments. Under low light conditions, *Z. mays* exposed to P1 showed contrasting responses depending on temperature. At 25˚C, P1 recorded a positive net assimilation rate at low photosynthetically active radiation (PAR), whereas at 30˚C, assimilation under P1 was negative, indicating strong temperature–water stress interaction. These results confirm that the apparent high initial assimilation under P1 occurred only under moderate temperature conditions.

Neolamarckia cadamba showed a clear response to both precipitation and temperature across treatments. At 25˚C, photosynthetic performance was relatively stable across precipitation levels, although low and high rainfall slightly constrained assimilation at low light. At 30˚C, temperature sensitivity became more pronounced, with P2 supporting the highest assimilation rates, while low and P3 reduced performance. In Figure 3, *N. cadamba* exhibited a typical saturating A–Li response, with net photosynthesis increasing with light and approaching a plateau at 1000–1500 μmol photons m^{-2} s^{-1} at 25˚C. Precipitation significantly influenced the magnitude of assimilation, with low and normal rainfall supporting higher photosynthetic rates than high rainfall at moderate light levels. At 30˚C, temperature sensitivity became more pronounced, and P2 resulted in the highest assimilation across all treatments, while both low and P3 constrained photosynthetic performance.

Figure 4 shows that *N. cadamba* exhibited saturating photosynthetic light-response curves across all precipitation treatments at 25˚C. Photosynthetic performance increased with irradiance under all rainfall conditions, although P3 showed reduced assimilation at low light but the highest rates at high irradiance. At 30˚C, temperature-precipitation interactions became more pronounced. P2 supported the highest photosynthetic performance across light levels, while both low and P3 constrained assimilation at low light but recovered under high irradiance.

3.2 | Photosynthetic gas exchange of *Z. mays* under monoculture system and agroforestry system (A–Li curve at 25˚C and 30˚C, 400 ppm CO_2)

Analysis of gas exchange parameters of *Z. mays* revealed significant effects of precipitation, temperature, and cropping system on net CO_2 assimilation (A), transpiration (E), stomatal conductance (G_s), and WUE (Table 1). Agroforestry systems consistently showed higher A and WUE under P1, particularly at elevated temperatures, indicating improved drought resilience compared with monoculture. In contrast, monocultures exhibited higher E and G_s, reflecting greater water loss under stress conditions. Significant interactions among precipitation, temperature, and system confirmed that agroforestry moderated the negative effects of combined heat and water stress on maize physiological performance.

3.3 | Photosynthetic gas exchange of *Z. mays* under monoculture and agroforestry system (A–Li curve at 400 and 700 ppm CO_2)

The effects of precipitation, CO_2 concentration, and cropping system on the gas exchange parameters of *Z. mays*

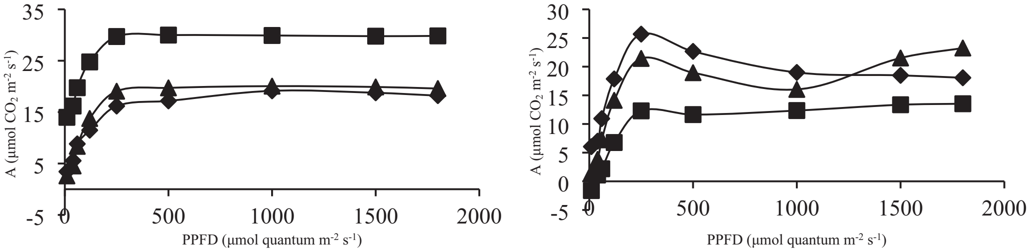

FIGURE 2 Photosynthetic light response (A-Li) curves of *Zea mays* (Agroforestry) under precipitation patterns, P1: Low precipitation, P2: Normal precipitation, and P3: High precipitation, measured at a constant intercellular CO_2 concentration of 400 ppm and leaf temperature of either 25˚C or 30˚C. Symbols for square represent P1: Low precipitation, pyramid represents P2: Normal precipitation, and diamond represents P3: High precipitation. PPFD, photosynthetic photon flux density.

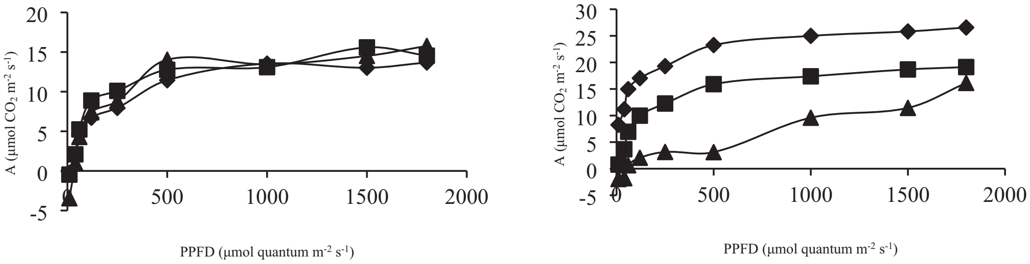

FIGURE 3 Photosynthetic light response (A-Li) curves of *Neolamarckia cadamba* (only tree) under three precipitation patterns. P1: Low precipitation, P2: Normal precipitation, and P3: High precipitation measured at a constant intercellular CO_2 concentration of 400 ppm and leaf temperature of either 25˚C or 30˚C. Note: symbols for square represent P1: low precipitation, pyramid represents P2: normal precipitation, and diamond represents P3: high precipitation. PPFD, photosynthetic photon flux density.

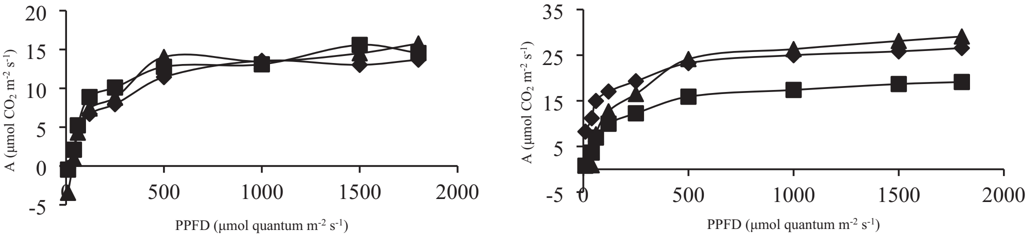

FIGURE 4 Photosynthetic light response (A-Li) curves of *Neolamarckia cadamba* (agroforestry) under three precipitation patterns, P1: Low precipitation, P2: Normal precipitation, and P3: High precipitation, measured at a constant intercellular CO_2 concentration of 400 ppm and leaf temperature of either 25˚C or 30˚C. Symbols for square represent P1: low precipitation, pyramid represent P2: normal precipitation, and diamond represents P3: high precipitation. PPFD, photosynthetic photon flux density.

summarized in Table 2. Net CO_2 assimilation (A) was significantly influenced by precipitation and agricultural system, with a significant three-way interaction indicating that CO_2 effects depended on both rainfall and system type. Under P1, monoculture generally showed higher A, whereas under P3, agroforestry benefited more from elevated CO_2. E was strongly affected by precipitation and CO_2 concentration, with agroforestry showing greater variability and a reduction in E under elevated CO_2 at high rainfall. Stomatal conductance (Gs) exhibited no main treatment effects but showed a precipitation-dependent response to CO_2. WUE displayed clear system-specific patterns, with monoculture performing better under low to normal rainfall, while agroforestry achieved higher WUE under P3 at elevated CO_2.

3.4 | Photosynthetic gas exchange of *N. cadamba* in monoculture system and agroforestry system (A–Li curve at 25˚C and 30˚C, 400 ppm)

Table 3 present the effects of precipitation, temperature, and cropping system on gas exchange parameters of *N. cadamba*. Net CO_2 assimilation (A) was primarily influenced by temperature and its interaction with precipitation, with a significant three-way interaction indicating that temperature effects depended on both rainfall and system type. At 25˚C, monocultures generally showed higher assimilation under normal and P3, whereas agroforestry performed better under P1. This advantage diminished at 30˚C, where

TABLE 1 Variation in instantaneous gas exchange performances (net CO_2 assimilation rate or A, µmol CO_2 m^{-2} s^{-1}; transpiration rate or E, mol H_2O m^{-2} s^{-1}; stomatal conductance or Gs, mmol H_2O m^{-2} s^{-1} and water use efficiency or WUE, µmol CO_2 mmol-1 H_2O) of *Zea mays* in monoculture system and *Zea mays* in an agroforestry system with three different precipitation levels: P1: Low precipitation, P2: Normal precipitation, and P3: High precipitation.

	System (S)										
	***Zea mays* in monoculture system**		***Zea mays* in agroforestry system**								
	Temperature (T)				***F*-value**						
Precipitation patterns (P)	**25˚C**	**30˚C**	**25˚C**	**30˚C**	**P**	**T**	**S**	**P × T**	**P × S**	**T × S**	**P × T × S**
	Net CO_2 assimilation rate (A) (µmol CO_2 m^{-2} s^{-1})										
Low	22.54 ± 2.70a,A	18.28 ± 3.37b,B	31.88 ± 2.11a,B	40.68 ± 2.92a,A	350.86***	14.28**	174.30***	1.35 ns	202.51***	27.54**	42.89***
Normal	18.21 ± 3.21b,A	18.06 ± 0.91b,A	12.96 ± 0.73c,B	17.05 ± 5.09c,A							
High	19.59 ± 5.82ab,B	23.25 ± 4.61a,A	24.15 ± 7.94b,A	21.07 ± 1.46b,A							
	Transpiration rate (E) (mol H_2O m−2 s−1)										
Low	5.45 ± 0.68a,A	4.87 ± 0.91a,A	1.28 ± 0.24b,A	1.46 ± 0.04c,A	62.10**	7.45*	95.03***	9.16*	76.42**	8.71**	10.56***
Normal	5.27 ± 0.51a,A	4.72 ± 0.30a,A	3.38 ± 0.33a,B	5.85 ± 1.56a,A							
High	3.92 ± 0.86b,A	3.37 ± 0.87b,A	2.78 ± 0.36ab,A	3.06 ± 0.52b,A							
	Stomatal conductance (Gs) (mmol H_2O m−2 s−1)										
Low	0.095 ± 0.009a,A	0.077 ± 0.01ab,A	0.031 ± 0.01c,A	0.017 ± 0.001a,B	75.19***	0.49 ns	22.48**	15.96**	41.02**	15.59***	3.71*
Normal	0.099 ± 0.01a,A	0.100 ± 0.04a,A	0.096 ± 0.01a,B	0.150 ± 0.04a,A							
High	0.103 ± 0.02a,A	0.054 ± 0.03b,B	0.068 ± 0.01b,A	0.066 ± 0.01b,A							
	Water use efficiency (WUE) (µmol CO2 mmol−1 H_2O)										
Low	4.54 ± 0.78b,A	4.35 ± 0.82b,A	11.80 ± 3.17a,B	27.80 ± 1.11a,A	281.83***	91.97***	359.14***	79.49***	246.80***	29.22**	87.58***
Normal	3.45 ± 0.45ab,A	3.78 ± 0.51b,A	3.88 ± 0.30c,A	4.09 ± 2.37c,A							
High	5.72 ± 2.28a,A	7.16 ± 0.88a,A	9.44 ± 4.00b,A	7.31 ± 1.35b,B							

Note: Measurements were made at a photosynthetic photon flux density (PPFD) of 1500 µmol photon m^{-2} s^{-1}, an internal air CO_2 concentration of 400 ppm, and leaf temperature of either 25˚C or 30˚C. The data were expressed as means ± standard error, SE. *$p < 0.05$; **$p < 0.01$; and ***$p < 0.001$. Means with different lowercase letter within the same row showed differences between temperatures or CO_2 concentrations, while means with different uppercase letter within same column showed differences between precipitation patterns.

Abbreviation: ns, no significant.

TABLE 2 Variation in instantaneous gas exchange performances (net CO_2 assimilation rate or A, µmol CO_2 m^{-2} s^{-1}; transpiration rate or E, mol H_2O m^{-2} s^{-1}; stomatal conductance or Gs, mmol H_2O m^{-2} s^{-1} and water use efficiency or WUE, µmol CO_2 mmol-1 H_2O) of *Zea mays* in monoculture system and *Zea mays* in an agroforestry system with three different precipitation levels: P1: Low precipitation, P2: Normal precipitation, and P3: High precipitation.

	System (S)										
	***Zea mays* in monoculture system**		***Zea mays* in Agroforestry system**								
	CO_2 concentration (C)				***F*-value**						
Precipitation patterns (P)	**400 ppm**	**700 ppm**	**400 ppm**	**700 ppm**	**P**	**C**	**S**	**P × C**	**P × S**	**C × S**	**P × C × S**
	Net CO_2 assimilation rate (A) (µmol CO_2 m^{-2} s^{-1})										
Low	21.263 ± 3.68ab,A	16.567 ± 2.63a,B	6.8897 ± 1.32b,B	12.254 ± 4.33b,A	9.13**	2.90 ns	9.33**	20.33***	2.23 ns	1.20 ns	6.85*
Normal	34.797 ± 1.87a,A	18.676 ± 7.90a,B	18.309 ± 2.18ab,A	17.972 ± 3.31ab,A							
High	16.339 ± 0.57b,A	17.165 ± 0.37a,A	29.127 ± 9.45a,A	25.235 ± 6.89a,A							
	Transpiration rate (E) (mol H_2O m^{-2} s^{-1})										
Low	3.1535 ± 0.47b,A	3.55 ± 0.27a,A	11.036 ± 6.97a,A	11.064 ± 4.00a,A	34.17***	146.51***	1.91 ns	40.90***	8.23*	23.30**	9.53**
Normal	2.6538 ± 1.21b,A	3.043 ± 0.74a,A	5.2294 ± 1.75b,A	4.4943 ± 1.52b,A							
High	3.8515 ± 0.87a,A	4.1881 ± 0.08a,A	7.2317 ± 0.95ab,A	2.0124 ± 0.29c,B							
	Stomatal conductance (Gs) (mmol H_2O m^{-2} s^{-1})										
Low	0.0790 ± 0.01b,B	0.0829 ± 0.007a,A	0.2315 ± 0.16a,B	0.0635 ± 0.02b,A	1.51 ns	0.04 ns	0.11 ns	3.85*	0.43 ns	0.15 ns	0.59 ns
Normal	0.0763 ± 0.01b,A	0.0709 ± 0.01b,A	0.1429 ± 0.09b,A	0.1546 ± 0.05a,A							
High	0.0947 ± 0.02a,A	0.0995 ± 0.005a,A	0.0128 ± 0.005b,B	0.0467 ± 0.005b,A							
	Water use efficiency (WUE) (µmol CO_2 $mmol^{-1}$ H_2O)										
Low	10.272 ± 4.15b,A	4.9274 ± 1.12b,B	3.0613 ± 2.49b,A	1.7079 ± 0.93c,B	4.99*	14.02**	1.61*	18.32***	8.96*	14.24**	2.90 ns
Normal	21.595 ± 10.31a,A	6.5982 ± 3.44a,B	4.4645 ± 1.55a,A	5.4451 ± 2.13b,A							
High	4.7464 ± 1.16c,A	4.1016 ± 0.11b,A	4.4049 ± 1.77a,B	13.632 ± 5.51a,A							

Note: Measurements were made at a photosynthetic photon flux density (PPFD) of 1500 µmol photon m^{-2} s^{-1}, an internal air CO_2 concentration of either 400 or 700 ppm and leaf temperature at 25°C. The data were expressed as means ± standard error, SE. *$p < 0.05$; **$p < 0.01$; and ***$p < 0.001$. Means with different lowercase letters within the same row showed differences between temperatures or CO_2 concentrations, while means with different uppercase letters within same column showed differences between precipitation patterns.

Abbreviation: ns, no significant.

TABLE 3 Variation in instantaneous gas exchange performances (net CO_2 assimilation rate or A, µmol CO_2 m^{-2} s^{-1}; transpiration rate or E, mol H_2O m^{-2} s^{-1}; stomatal conductance or Gs, mmol H_2O m^{-2} s^{-1} and water use efficiency or WUE, µmol CO_2 mmol-1 H_2O) of *Neolamarckia cadamba* in monoculture system and *Neolamarckia cadamba* in an agroforestry system with three different precipitation levels: P1: Low precipitation, P2: Normal precipitation, and P3: High precipitation.

	System (S)										
	***Neolamarckia cadamba* in monoculture system**		***Neolamarckia cadamba* in agroforestry system**								
	Temperature (T)				***F*-value**						
Precipitation patterns (P)	**25˚C**	**30˚C**	**25˚C**	**30˚C**	**P**	**T**	**S**	**P × T**	**P × S**	**T × S**	**P × T × S**
	Net CO_2 assimilation rate (A) (µmol CO_2 m^{-2} s^{-1})										
Low	20.14 ± 3.29b,A	17.00 ± 2.53a,B	24.65 ± 4.49a,A	14.24 ± 6.26ab,B	0.40 ns	11.55***	2.44 ns	3.96*	0.46 ns	4.05*	9.66***
Normal	28.49 ± 1.69a,A	13.08 ± 8.07b,B	12.28 ± 0.73b,A	16.38 ± 5.09a,A							
High	24.65 ± 4.49ab,A	14.24 ± 6.26b,B	23.25 ± 3.59ab,A	13.24 ± 4.06b,B							
	Transpiration rate (E) (mol H_2O m^{-2} s^{-1})										
Low	4.21 ± 0.84a,A	3.89 ± 0.73a,A	2.99 ± 0.36ab,A	3.27 ± 0.52ab,A	9.56***	15.54***	22.22***	14.24***	2.62*	0.032 ns	4.18*
Normal	4.12 ± 0.86a,A	2.65 ± 1.37b,B	3.59 ± 0.33a,B	6.06 ± 1.56a,A							
High	2.99 ± 0.36b,A	3.27 ± 0.52a,A	2.75 ± 0.26b,A	3.07 ± 0.32b,A							
	Stomatal conductance (Gs) (mmol H_2O m^{-2} s^{-1})										
Low	0.11 ± 0.01a,A	0.10 ± 0.02a,A	0.08 ± 0.01ab,A	0.09 ± 0.01ab,A	4.75*	0.002 ns	1.18 ns	0.12 ns	12.98***	11.63***	2.68*
Normal	0.10 ± 0.02a,A	0.07 ± 0.03a,A	0.11 ± 0.01a,B	0.16 ± 0.04a,A							
High	0.08 ± 0.01a,A	0.08 ± 0.01a,A	0.06 ± 0.01b,A	0.07 ± 0.01b,A							
	Water use efficiency (WUE) (µmol CO_2 $mmol^{-1}$ H_2O)										
Low	5.31 ± 0.96b,A	5.80 ± 1.30ab,A	8.44 ± 1.90a,A	4.69 ± 2.47a,B	0.28 ns	0.25 ns	3.30 ns	1.16 ns	6.23**	0.45 ns	1.06 ns
Normal	7.76 ± 2.17ab,A	6.81 ± 3.51a,A	3.45 ± 0.25b,A	3.73 ± 2.17b,A							
High	8.44 ± 1.90a,A	4.69 ± 2.47b,B	5.64 ± 1.42ab,A	4.49 ± 1.54a,A							

Note: Measurements were made at a photosynthetic photon flux density (PPFD) of 1500 µmol photon m^{-2} s^{-1}, an internal air CO_2 concentration of 400 ppm and leaf temperature of either 25˚C or 30˚C. The data were expressed as means ± standard error, SE. $*p < 0.05$; $**p < 0.01$; and $***p < 0.001$. Means with different lowercase letters within the same row showed differences between temperatures or CO_2 concentrations, while means with different uppercase letters within same column showed differences between precipitation patterns.

Abbreviation: ns, no significant.

assimilation declined across both systems, indicating increased temperature sensitivity.

E was significantly affected by precipitation, temperature, and system, with monocultures generally exhibiting higher E than agroforestry, except under P2 at elevated temperature. Stomatal conductance (Gs) showed precipitation- and system-dependent responses, with agroforestry maintaining higher Gs under P2 at 30˚C, while monoculture showed a decline. WUE was mainly driven by the interaction between precipitation and system, with agroforestry achieving higher WUE under P1, although this advantage was reduced under normal rainfall.

3.5 | Photosynthetic gas exchange of *N. cadamba* under monoculture system and agroforestry system (A–Li curve at 400 and 700 ppm CO_2)

Table 4 reveals the effects of precipitation, CO_2 concentration, and cropping system on the gas exchange responses of *N. cadamba*. Net CO_2 assimilation (A) was significantly influenced by precipitation, with contrasting responses to elevated CO_2 depending on rainfall conditions. In monoculture, assimilation was generally higher at ambient CO_2 under low and P2, whereas elevated CO_2 enhanced A under P3. In contrast, agroforestry systems showed relatively stable assimilation across CO_2 levels, indicating lower sensitivity to CO_2 variation.

E was strongly affected by precipitation, with monocultures exhibiting greater variability and higher E under low rainfall and elevated CO_2. Agroforestry systems maintained more stable transpiration across CO_2 treatments, suggesting improved regulation of water loss. Stomatal conductance (Gs) responded primarily to precipitation, with monocultures showing stronger CO_2-dependent shifts than agroforestry.

WUE was mainly driven by precipitation and its interaction with cropping system and CO_2. Monocultures achieved higher WUE under ambient CO_2 at low and P2, whereas agroforestry systems attained comparatively higher WUE under P3 at elevated CO_2.

4 | DISCUSSION

4.1 | Interactive effects of temperature and precipitation on photosynthetic light response in *Z. mays* and *N. cadamba*

In the present study, the influence of temperature and precipitation on the photosynthetic light response (A–Li curves) of *Z. mays* and *N. cadamba* was investigated under two temperature conditions (25˚C and 30˚C) and three water treatments (P1–P3) in both monocultures and agroforestry systems. Significant interactions between precipitation and temperature were found in the photosynthetic performance of both species, reflecting differential physiological responses across environmental gradients. These interactive effects confirm our hypothesis that precipitation, temperature, and cropping system jointly regulate photosynthetic performance, with agroforestry providing greater physiological buffering under combined heat and water stress.

For *Z. mays* in monoculture at 25˚C, the light response curves showed that P1 resulted in an assimilation rate of 13.99 µmol CO_2 m^{-2} s^{-1} at 10 PAR, which increased to 29.99 µmol CO_2 m^{-2} s^{-1} up to 500 PAR and then reached a plateau (~29.83 at 1800 PAR). In contrast, P2 and P3 showed significantly lower assimilation at higher PAR: P2 reached only 19.14 µmol CO_2 m^{-2} s^{-1} at 1000 PAR and stagnated at 18.21, while P3 gradually increased to 20.05 at 1000–1800 PAR. The observed increase in photosynthetic performance under mild water stress is consistent with previous studies showing that moderate stress can enhance photosynthetic efficiency through improved stomatal regulation and optimization of carbon fixation (Ainsworth & Long, 2020; Blum, 2017; Chaves et al., 2009; Flexas et al., 2016).

At 30˚C, the influences of precipitation shifted significantly. In P1, assimilation at 10 PAR fell into the negative range (−1.61 µmol CO_2 m^{-2} s^{-1}) and increased to a reduced assimilation at strong light of 13.53 µmol CO_2 m^{-2} s^{-1}, underlining a detrimental interaction between precipitation and temperature. In contrast, P2 showed a robust recovery: 6.05 at 10 PAR, increasing to 25.67 at 250 PAR and stabilizing at 18–22 µmol CO_2 m^{-2} s^{-1} (500–1500 PAR). P3 mirrors this pattern with a moderate peak (~23.25 at 1800 PAR). These data reflect the central role of soil moisture in maintaining photosynthesis under heat stress and support the findings that adequate water mitigates stomatal limitations and thermal impairment in maize (*Z. mays*) under elevated temperatures (Simiyu et al., 2021). The interaction between temperature and precipitation was notable as the differences in the magnitude of photosynthetic rate and saturation PAR between P1 and P2/P3 were steeper at 30˚C, implying that maize physiological plasticity is modulated by both water availability and heat stress. This agrees with Fan et al. (2024), who found that temperature enhances stomatal closure under drought, thereby increasing the decline in assimilation efficiency.

The photosynthetic response of *N. cadamba* to temperature and precipitation appears to be primarily regulated by stomatal behavior and internal carbon balance. Under adequate moisture, elevated temperature enhanced carbon assimilation, likely through improved stomatal conductance and enzymatic activity (Cheah & Teh, 2020). In contrast, precipitation extremes constrained photosynthesis, probably due to stomatal closure under water stress or increased photorespiratory losses under excess moisture. Similar physiological mechanisms have been reported for tropical woody species under

TABLE 4 Variation in instantaneous gas exchange performances (net CO_2 assimilation rate or A, µmol CO_2 m^{-2} s^{-1}; transpiration rate or E, mol H_2O m^{-2} s^{-1}; stomatal conductance or Gs, mmol H_2O m^{-2} s^{-1} and water use efficiency or WUE, µmol CO_2 mmol-1 H_2O) of *Neolamarckia cadamba* in monoculture system and *Neolamarckia cadamba* in an agroforestry system with three different precipitation levels: P1: Low precipitation, P2: Normal precipitation, and P3: High precipitation.

	System (S)										
	***Neolamarckia cadamba* in monoculture system**		***Neolamarckia cadamba* in agroforestry system**								
	Temperature (˚C)				***F*-value**						
Precipitation patterns (P)	**400 ppm**	**700 ppm**	**400 ppm**	**700 ppm**	**P**	**C**	**S**	**P × T**	**P × S**	**C × S**	**P × C × S**
	Net CO_2 assimilation rate (A) (µmol CO_2 m^{-2} s^{-1})										
Low	43.61 ± 14.15ab,A	37.43 ± 10.33a,B	15.67 ± 0.57ab,A	16.50 ± 0.37a,A	38.38*	0.50	0.85	0.67	0.60	0.26	0.05
Normal	52.58 ± 24.1a,A	26.91 ± 4.96b,B	33.46 ± 1.87a,A	17.78 ± 7.71a,B							
High	10.31 ± 1.98b,B	18.35 ± 6.48c,A	11.98 ± 4.22b,B	16.52 ± 0.75a,A							
	Transpiration rate (E) (mol H_2O m^{-2} s^{-1})										
Low	3.96 ± 2.28ab,B	11.27 ± 2.28a,A	3.17 ± 0.34ab,A	3.63 ± 0.04ab,A	111.33*	1.78	0.31	0.05	2.10	0.85	0.36
Normal	5.44 ± 1.75a,A	4.49 ± 1.52b,A	2.59 ± 1.42b,A	3.25 ± 0.74b,A							
High	0.54 ± 0.25b,B	2.01 ± 0.29c,A	3.85 ± 0.87a,A	4.18 ± 0.08a,A							
	Stomatal conductance (Gs) (mmol H_2O m^{-2} s^{-1})										
Low	0.04 ± 0.03b,B	0.17 ± 0.05a,A	0.06 ± 0.01b,A	0.08 ± 0.01b,A	159.53*	0.26	2.08	1.38	0.19	0.05	0.33
Normal	0.04 ± 0.02b,B	0.08 ± 0.02ab,A	0.09 ± 0.01ab,A	0.09 ± 0.01b,A							
High	0.14 ± 0.09a,A	0.06 ± 0.01b,B	0.11 ± 0.02a,A	0.11 ± 0.01a,A							
	Water use efficiency (WUE) (µmol CO_2 $mmol^{-1}$ H_2O)										
Low	20.19 ± 8.04ab,A	3.48 ± 0.36b,B	5.02 ± 0.35ab,A	4.54 ± 0.05ab,B	40.35*	0.01	0.92	0.32	1.07	0.21	0.02
Normal	10.65 ± 3.91c,A	8.15 ± 3.20a,A	6.67 ± 36.3a,A	5.80 ± 3.05a,B							
High	24.82 ± 3.53a,A	9.01 ± 3.15a,B	2.98 ± 0.85b,B	3.95 ± 0.20b,A							

Note: Measurements were made at a photosynthetic photon flux density (PPFD) of 1500 µmol photon m^{-2} s^{-1}, an internal air CO_2 concentration of either 400 or 700 ppm, and leaf temperature at 25˚C. The data were expressed as means ± standard error, SE. *$p < 0.05$; **$p < 0.01$; and ***$p < 0.001$. Means with different lowercase letters within the same row showed differences between temperatures or CO_2 concentrations, while means with different uppercase letters within the same column showed differences between precipitation patterns.

Abbreviation: ns, no significant.

combined heat and water stress (Didaran et al., 2024; Y. Wang et al., 2023). A significant precipitation effect was found, suggesting that *N. cadamba* is less affected by moderate moisture fluctuations at 25˚C but shows a suppressive response at extreme temperatures.

At 30˚C the reaction shifted considerably. P1 started at 0.77 and increased to 19.12 until saturation; P2 started at 8.25 and reached an impressive 26.56 at 1800 PAR; P3 started negative (−1.95) but climbed to 16.13. The increased initial assimilation in P2 shows an interaction between temperature and precipitation, as optimal moisture allows for increased photosynthetic capacity upon warming, likely through improved stomatal conductance and enzymatic efficiency (Ainsworth & Long, 2020). Similar patterns were seen in the A–Ci curves in agroforestry systems compared to monocultures. *Zea mays* showed weak CO_2 responsiveness (700 ppm), consistent with C_4 physiology, but *N. cadamba* showed improved performance when ambient CO_2 was supplemented with balanced rainfall, suggesting that CO_2-precipitation interactions are important in the physiology of tropical agroforestry trees.

Maize (*Z. mays*) shows optimal assimilative capacity under mild drought and moderate temperatures (25˚C), but this advantage is reversed under heat stress, with better performance under normal or high rainfall. *Neolamarckia cadamba* shows minimal variation at 25˚C but exhibits increased photosynthesis under warming conditions when water supply is optimal, indicating synergistic temperature × precipitation effects. The interactions between precipitation and temperature are strong in both species, confirming that water availability significantly alters responses to heat stress. The system context (monoculture vs. agroforestry) further modulated the responses. Although the detailed A–Ci data extend beyond this section, previous studies (Ainsworth & Long, 2020) suggest that agroforestry increases resilience by regulating the microclimate, which is consistent with our results in tree culture systems.

Ecologically, maintaining sufficient moisture becomes critical as temperatures rise. Cultivation strategies that integrate irrigation or drought-resistant varieties into monocultures can mimic the benefits of agroforestry systems. Conversely, agroforestry with *N. cadamba* can buffer heat drought stress and increase ecosystem resilience.

4.2 | Net CO_2 assimilation responses to precipitation, temperature, and CO_2 in monoculture and agroforestry systems

This study also investigated how precipitation patterns (low, normal, and high), temperature (25˚C and 30˚C), CO_2 concentration (400 ppm and 700 ppm), and agriculture system (monoculture vs. agroforestry) jointly affect photosynthetic gas exchange of *Z. mays* and *N. cadamba*. The key variables, net CO_2 assimilation rate (A), E, stomatal conductance (G_s), and WUE, showed significant main effects and interactions (precipitation × temperature, precipitation × system, temperature × system, and precipitation × temperature × system), indicating complex plant responses under climate stressors.

In *Z. mays*, net CO_2 assimilation rate (A) was significantly affected by precipitation, temperature, and system, with a strong three-way interaction ($P \times T \times S$: $F = 42.89$, $p < 0.001$). Under low rainfall, maize in agroforestry achieved significantly higher A (31.88 ± 2.11 at 25˚C; 40.68 ± 2.92 at 30˚C) than in monoculture (22.54 ± 2.70; 18.28 ± 3.37). This is consistent with the results of Hussain et al. (2020), which demonstrated increased photosynthetic performance in shaded or integrated agriculture systems under drought. The significant P × T interaction illustrates how increased temperature suppresses A more strongly in monocultures under drought, while agroforestry buffers this effect. This is also consistent with the findings of H. Wang et al. (2024), who reported that diversified systems mitigate heat effects through microclimate mitigation.

In the monoculture under CO_2 environment, maize A showed a significant P × C × S interaction ($F = 6.85$, $p < 0.05$). Under low rainfall, A decreased from 21.26 ± 3.68 (400 ppm) to 16.57 ± 2.63 (700 ppm) in the monoculture, indicating decreasing gains with CO_2 enrichment. This is consistent with C_4 maize, which has a limited response to CO_2 fertilization (Leakey, 2009; Liu et al., 2022). Conversely, agroforestry showed an increase in A at 700 ppm during high rainfall, likely due to improved microclimate and moisture buffering (Sneha Dobhal et al., 2024). Thus, the CO_2 × system × precipitation interactions mirror the interactions also reported by H. Wang et al. (2024) and Ainsworth and Long (2020). In *N. cadamba*, A was significantly affected by precipitation × temperature ($F = 3.96$, $p < 0.05$) and the three-way interaction ($F = 9.66$, $p < 0.001$).

Agroforestry yielded higher A than monocultures at low rainfall at 25˚C (24.65 vs. 20.14), but this advantage disappeared at 30˚C probably due to resource competition under heat stress. The assimilation performance of *N. cadamba* in monoculture was higher at 400 ppm than at 700 ppm when rainfall was normal, suggesting an interaction between CO_2 and humidity, consistent with the results of Zewdinesh Damtew Zigene (2023).

4.3 | Impact of precipitation, temperature, and CO_2 on E in monoculture and agroforestry

In maize, E varied significantly across rainfall ($F = 62.10$, $p < 0.01$), system ($F = 95.03$, $p < 0.001$), and their interaction ($F = 76.42$, $p < 0.01$). The monoculture had a much higher E at low rainfall at 25˚C (5.45 ± 0.68 mmol H_2O), while the agroforestry had a stable low E (1.28 ± 0.24).

This supports Li and Liu (2022), who found that agroforestry moderates evapotranspiration in the field. Under P3 at 30°C, the E of monoculture decreased (to 3.37 ± 0.87), while agroforestry remained stable (3.06 ± 0.52), indicating P × T × S interactions ($F = 9.16$, $p < 0.05$) and reflecting buffering of temperature and drought (H. Wang et al., 2024). In the CO_2 enrichment experiment, maize E was affected by precipitation, CO_2 concentration, and their interaction ($F = 40.90$, $p < 0.001$). Notably, in agroforestry under P3, E decreased from 7.23 to 2.01 mmol H_2O m^{-2} s^{-1} as CO_2 concentration increased, which indicates a stronger down-regulation of stomata under elevated CO_2 in diversified systems. While some studies (Moore et al., 2021) show universal stomatal closure, our results suggest system-specific responses.

In *N. cadamba*, rainfall, temperature, and system had a significant effect on E. Unexpectedly, agroforestry under normal rainfall and 30°C showed high E (6.06), possibly due to hydraulic redistribution between the cultivated species. This is consistent with Li and Liu (2022) the P × T interaction suggests that plant behavior dynamically adapts under combined stress factors.

4.4 | Stomatal conductance responses to precipitation, temperature, and CO_2 in monoculture and agroforestry system

Stomatal conductance (G_s) of maize varied significantly between rainfall, system, and P × T, T × S interactions. Monocultures had higher G_s (0.095 ± 0.009) than agroforestry systems (0.031 ± 0.01) under P1 at 25°C, confirming the lower water loss in diversified systems. P3 at 30°C reduced G_s in monocultures but not in agroforestry systems, again reflecting microclimate buffering (Lu et al., 2023). In maize under CO_2 enrichment, no main effects of P, C, or S on G_s occurred, but a P × C interaction ($F = 3.85$, $p < 0.05$) was present, supporting the contention that increased CO_2 closure mechanisms vary with soil moisture. In *N. cadamba*, G_s was influenced by P, its interactions with the system, and temperature. Under P3, G_s remained uniformly low (0.06–0.08 mmol), emphasizing stomatal regulation under excess water. Agroforestry maintained or increased G_s under moderate stress, suggesting adaptive plasticity via species interactions, supporting Silva et al. (2020).

4.5 | WUE responses to precipitation, temperature, and CO_2 in monoculture and agroforestry system

WUE showed the strongest variability. For maize, the P × T ($F = 79.49$, $p < 0.001$), P × S ($F = 246.80$, $p < 0.001$), and P × T × S ($F = 87.58$, $p < 0.001$) effects were significant. Remarkably, under low rainfall and 30°C, agroforestry achieved a WUE of 27.80 ± 1.11 times more than monoculture (4.35 ± 0.82), emphasizing the advantage of agroforestry in carbon gain per water loss. This confirms Molénat et al. (2023), who found that diversified systems increase WUE under drought and heat stress. Under CO_2 enrichment, the maize monoculture showed higher WUE under low normal rainfall, but agroforestry performed better under high rainfall with 700 ppm CO_2 suggesting an interplay between moisture and CO_2 as drivers of efficiency, consistent with Sheppard et al. (2020).

In *N. cadamba*, precipitation × system had a significant effect on WUE ($F = 6.23$, $p < 0.01$). At low rainfall, agroforestry achieved higher WUE than monoculture, a result consistent with Jose (2009), who emphasized the resource optimization of agroforestry. However, under normal rainfall, the monoculture showed higher WUE, probably due to higher assimilation per water loss at optimum moisture. Temperature had no independent effect, suggesting that WUE is more water- and system-dependent.

4.6 | Interactive effects of climate and agricultural system on photosynthesis in maize and *N. cadamba*

The data clearly show that agroforestry confers resilience benefits to both maize and *N. cadamba* under combined abiotic stresses. In maize, agroforestry maintained higher or stable gas exchange rates during drought and heat, as evidenced by lower variation in E, G_s was maintained, and WUE was significantly increased. This suggests that integrated systems can maintain productivity under climate extremes by buffering the microclimate and reducing plant hydraulic stress (Hussain et al., 2020). *Neolamarckia cadamba* also benefited from agroforestry, especially under low rainfall. Improved WUE and stabilized G_s under moderate water availability underline the photosynthetic plasticity of the species in diversified systems, a promising feature for the sustainable design of agroforestry (Jose, 2009; Silva et al., 2020).

The limited response to CO_2 fertilization in maize under drought conditions reflects broader meta-analyses showing that C_4 species exhibit low sensitivity to CO_2 enrichment under field conditions (Leakey et al., 2009). However, agroforestry altered these trends: maize under high rainfall and elevated CO_2 showed increased assimilation, highlighting that system context influences CO_2 response (Ainsworth & Long, 2020). In *N. cadamba*, variable CO_2 × precipitation patterns in assimilation and WUE highlight the importance of resource balance: positive responses occurred when sufficient moisture was present, suggesting that water availability is necessary for CO_2 benefits to manifest (Jones, 2024).

Although the experimental design was robust in the manipulation of rainfall, temperature, CO_2 and agriculture systems, certain limitations must be acknowledged. Agroforestry was represented by only one tree species (*N. cadamba*). The inclusion of multiple tree species or functional groups could increase buffering capacity and reveal species-specific trait interactions (Nair, 2011). Another limitation of this study is that it was conducted as a short-term pot experiment under controlled shelter-house conditions. While this approach allowed precise manipulation of temperature, CO_2, and precipitation, it may not fully capture long-term plant responses, root dynamics, or soil, plant, and atmosphere interactions observed under field conditions. Therefore, caution is required when extrapolating these findings to large-scale or long-term agroforestry systems. Studies over multiple seasons or generations are needed to assess the effects of downregulation and yield responses (Norby et al., 2005).

5 | CONCLUSION

This study demonstrates that agroforestry integration with *N. cadamba* enhances the photosynthetic resilience of maize under combined climate stresses, particularly drought and elevated temperature. The findings highlight the capacity of agroforestry systems to buffer physiological stress and improve water-use efficiency. Agroforestry systems consistently outperformed monocultures, enhancing carbon uptake and WUE, especially under low rainfall and elevated temperature stress. *N. cadamba* demonstrated notable physiological resilience in agroforestry system, particularly under water-limited conditions, suggesting its adaptability within diversified systems. These findings emphasize agroforestry's potential to buffer crops against climate variability, stabilize gas exchange, and improve water efficiency. However, benefits varied depending on environmental conditions, reinforcing the need for tailored, location-specific management. To optimize agroforestry's impact, future research should extend these findings through long-term field trials that evaluate not only physiological responses but also crop yield, soil properties, and soil–plant interactions to better assess the agronomic and ecological benefits of agroforestry systems.

AUTHOR CONTRIBUTIONS

Romia Rona Tagang: Conceptualization; data curation; formal analysis; investigation; methodology; writing—original draft. **Hollena Nori**: Conceptualization; investigation; methodology; supervision; writing—review and editing. **Walftor Dumin**: Conceptualization; investigation; methodology; supervision; writing—review and editing. **Wee Sze Yee**: Conceptualization; data curation; formal analysis; writing—review and editing. **Ho Wei Seng**: Conceptualization; writing—review and editing. **Mohamad Hilmi Ibrahim**: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; supervision; validation; writing—original draft; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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