Borneo Journal of Resource Science and Technology (2025), 15(2): 94-101
DOI: https:doi.org/10.33736/bjrst.8534.2025

The Potential of *Neolamarckia cadamba* Seedling in Improving Growth Performance and Yield of *Zea mays* under Different Precipitation Patterns

ROMIA RONA TAGANG[1], HOLLENA NORI[1], WALFTOR DUMIN[1], WEE SZE YEE[2], HO WEI SENG[1] & MOHAMAD HILMI IBRAHIM*[1]

[1]Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300, Kota Samarahan, Sarawak, Malaysia; [2]Institute of Biodiversity and Environmental Conservation, Universiti Malaysia Sarawak, 94300, Kota Samarahan, Sarawak, Malaysia;
*Corresponding author: imhilmi@unimas.my
Received: 31 December 2024 Accepted: 20 October 2025 Published: 31 December 2025

ABSTRACT

Climate change is altering rainfall, with more droughts and severe storms that harm agriculture. These shifts in temperature and precipitation disrupt soil moisture, which is essential for the growth of staple crops. Therefore, this study was conducted to investigate the effects of integrating *Neolamarckia cadamba* with *Zea mays* on growth performance under different precipitation patterns: low (T1), normal (T2) and high (T3). The experiment was conducted in a completely randomised block design (CRBD), with the first block representing *N. cadamba* integrated with *Z. mays* as agroforestry, the second block representing only *Z. mays* as a crop and the third block only *N. cadamba* as a tropical tree species. The growth parameters (number of leaves, diameter, plant height and chlorophyll content) were measured 120 days after planting and the yield parameters (fresh weight, dry weight, number of kernels, fresh weight of kernel, dry weight of kernel) were measured after harvesting. The results showed significant effects of rainfall and agroforestry integration on maize yield in term of dry weight, number of kernels, kernels fresh weight and kernel dry weight. Kernel yield parameters, including fresh weight and kernel number, were highest under T2 and T3 in the agroforestry (AGRO), indicating improved availability of resources and soil conditions by *N. cadamba*. In term of practices, AGRO produced higher chlorophyll (SPAD: 29.44±1.44 vs 22.47±2.31; $p < 0.05$) and dry weight (277.24±11.68 g vs 216.84±23.47 g; $p < 0.05$) than NON-AGRO. These results show an ecological trade-off such as in normal and wet conditions *N. cadamba* cools the canopy and conserves soil moisture, raising *Z. mays* performance while under drought, root water pre-emption and reduced light increase competition and depress kernel. At farm level, border or alley planting of *N. cadamba* with *Z. mays* can be promoted under normal and wet conditions, while wider spacing or soil-water conservation is advisable in dry conditions the policymakers can include maize and *N. cadamba* designs in agroforestry extension as part of climate-smart agriculture.

Keywords: Agroforestry, climate change, growth performance, precipitation pattern, *Zea mays*

INTRODUCTION

In response to growing concerns over climate change, the integration of agroforestry practices has gained attention as a sustainable solution to improve the resilience of agriculture. Agroforestry, the combination of trees with agricultural crops, has been shown to be a sustainable practice for agricultural productivity, restoring degraded land, and mitigating the effects of climate change (Jose, 2009; Das *et al*., 2024). By incorporating perennial woody plants into agricultural systems, agroforestry improves biodiversity, carbon sequestration and ecosystem resilience while supporting rural livelihoods (Lorenz & Lal, 2014; Zomer *et al*., 2016). This practice is particularly important in regions that are vulnerable to climate variability as it helps to maintain soil fertility and water availability for plant growth.

Climate change, especially the shift in precipitation patterns, poses a major challenge to agricultural systems worldwide. Anthropogenic activities such as deforestation, the burning of fossil fuels and greenhouse gas emissions have accelerated global warming and contribute to changing precipitation patterns and extreme weather events (Tang, 2019). Changes in precipitation patterns affect soil moisture availability, crop phenology and overall agricultural productivity and pose a threat to global food security (Hooper *et al*., 2005; Firdaus *et al*., 2018). In Malaysia, climate variability has led to prolonged droughts, excessive rainfall and flooding, disrupting agricultural cycles and crop yields (Tang, 2019).

Among agroforestry trees, *Neolamarckia cadamba*, also known as Kelempayan, is a potential tropical tree species due to its fast growth and deep root system that can help improve soil structure and nutrient cycling (Khatta *et al*., 2023). Its ability to adapt to different environmental conditions and improve soil properties makes it a suitable candidate for agroforestry systems, especially in areas with climatic stress (Khatta *et al*., 2023). On the other hand, *Zea mays* (maize) is a globally important cereal crop that is essential for food security and economic stability in many regions (Erenstein *et al*., 2022). However, maize production is very sensitive to climate variability, especially to changes in rainfall patterns. Insufficient rainfall or too much water can have a negative impact on the growth, development and yield of maize and exacerbate food insecurity in regions such as Malaysia (Alam *et al*., 2017).

Recent studies emphasise the role of rainfall in determining crop productivity, with rainfall variability posing a major challenge to food security (Wang *et al*., 2024). Changes in rainfall patterns due to climate change in the form of excessive rainfall or prolonged drought can affect the growth, yield and resilience of crops such as maize (Yin *et al*., 2016). *Zea mays* is highly sensitive to moisture extremes where drought can reduce yield by ~30–90% depending on timing and severity (Széles *et al.,* 2023). *Neolamarckia cadamba* can mitigate some negative effects through water regulation and soil stabilisation, making it an ideal candidate for integration into agroforestry (Wamalwa *et al*., 2021). Empirical evidence for the integration of *N. cadamba* and *Z. mays* in different rainfall regimes is still limited. Few studies examine both species simultaneously under low, normal and high precipitation to separate microclimatic benefits from subsurface water competition.

The aim of this study is to investigate the effects of *N. cadamba* integration on *Z. mays* growth and yield performance under different precipitation patterns. By assessing low (T1), normal (T2) and high (T3) rainfall, the study aims to provide data on whether the integration of agroforestry can improve crop resilience and productivity in changing climates. We hypothesise that integrating *N. cadamba* with *Z. mays* increases chlorophyll content, biomass, and kernel yield under normal and high precipitation, but shows neutral or negative effects under low precipitation because of water competition. We expect a significant interaction between cropping system and precipitation on growth and yield.

METHODOLOGY

Study Site

The 29ft (L) × 19ft (W) × 8ft (H) shelter was set up at the Faculty of Resource Science and Technology, UNIMAS. *Neolamarckia cadamba* and *Zea mays* were grown in the shelter house to minimise infestation by pests and to ensure uniform sunlight and water supply. The temperature in the shelter was 29 °C with a humidity of 76%, which was determined using a hygrometer.

Experimental Design

A complete randomised block design (CRBD) was conducted to minimise variability and increase the reliability of the results. The study consisted of three blocks with four replications. Each block assigned to one of the three rainfall treatments. The block plot was the integration of *N. cadamba* and *Z. mays* as agroforestry, the second block was only *Z. mays* as a crop and the third block was only *N. cadamba* as a tropical tree. Each agroforestry (AGRO) pot contained two seedlings (1 *N. cadamba* + 1 *Z. mays*; 1:1). Each NON-AGRO pot contained a single seedling (either *Z. mays* or *N. cadamba*). In AGRO pots, the centre-to-centre spacing between the two seedlings was 15 cm within the pot area. Across treatments, n = 4 pots per rainfall regime. These represent the different agricultural practices.

Baseline Soil Composition and Nutrient

Baseline soil (Nyalau series; *Typic paleudults*) was characterised before treatments. Texture was determined by the hydrometer method and classified as sandy clay loam. Soil pH (H_2O) was measured in a 1:2.5 soil-to-water suspension. Bulk density was measured by the core method (oven-dry mass/volume). Mineral N (NH_4^+–N and NO_3^-–N) was extracted with 2 M KCl (1:5, w/v) and determined using Hach colourimetric methods ammonia salicylate for NH_4^+–N (Hach 8155) and Nitrate by cadmium reduction/Griess for NO_3^-–N (Hach 8039/8171) on a Hach DR spectrophotometer. Available P was extracted with Bray-1 and measured colourimetrically. Total N was determined by the Kjeldahl method. Total organic carbon was analysed by the Walkley–Black method, and organic matter by loss on ignition. Summary values (means of three replicates) are reported in Table 1.

Table 1. Selected soil physico-chemical properties of Nyalau series (*Typic paleudults*) used in the study. Data are expressed as the means of three replications

Parameter	Value
pH in water	4.84
Exchangeable Ammonium NH_4^+	49.04 $mgkg^{-1}$
Available Nitrate NO_3^-	21.02 $mgkg^{-1}$
Available Phosphate	0.10 $mgkg^{-1}$
Total Nitrogen	0.11%
Bulk density	1.20 gcm^{-3}
Total Organic Carbon	6.00%
Organic matter	0.17%
Soil texture: Soil-sandy clays loam	

Precipitation Treatments

The three precipitation treatments were carefully simulated to reflect realistic environmental scenarios. Low precipitation (T1) included water reduction to mimic drought conditions, normal precipitation (T2) corresponded to average precipitation patterns typical of the region, and high precipitation (T3) simulated excessive rainfall from supplemental irrigation. Water was applied by hand to each pot using the average weekly rainfall in Kota Samarahan, Sarawak as the basis. The experiment tested three precipitation levels: the weekly average (W), W decreased by 30% (W−), and W increased by 30% (W+). For example, if the weekly total was 311 mm (approximate ± 30% range: highest 449 mm; lowest 212 mm), treatment volumes were set accordingly. Treatments were administered once every six days in the morning (07:00–09:00). To prevent desiccation, seedlings were also watered once daily.

Measuring the Variables

Growth performance and yield of *Z. mays* and *N. cadamba* were measured over 120 days after planting. The growth parameters included the number of leaves, plant height, stem diameter and chlorophyll, which were measured using a ruler, a tape measure, a digital calliper and a chlorophyll metre (SPAD 502, Plus, Konica Minolta). Yield metrics were assessed at harvest and included *Z. mays* fresh weight, *Z. mays* dry weight, number of kernels, kernel fresh weight and kernel dry. *Zea mays* were harvested fresh in the field and weighed using an electronic scale with an accuracy of 1 g. The grains on the stalk were shelled and weighed. Total dry matter (TDM) was determined by drying in a brown envelope in an oven at 65 °C until a constant weight was reached.

Data Analysis

The data were analysed using SAS Version 9 (SAS Institute Inc., Cary, NC, USA). Growth and yield of *Z. mays* were evaluated under three rainfall treatments where low is T1, normal is T2 and high is T3 for both AGRO and NON-AGRO systems. We used one-way ANOVA to test rainfall effects within each cropping system because rainfall was the single factor with three fixed levels and our primary interest was to compare T1, T2 and T3 within a given system. Duncan's Multiple Range Test (DMRT) identified differences among means at $\alpha = 0.05$. We used unpaired t-tests to compare AGRO versus NON-AGRO within the same rainfall regime, as units experienced the same watering schedule and could be matched; pairing increases power and controls between-unit variability. We checked normality (Shapiro–Wilk) and homogeneity of variances (Levene's). Results are reported as mean ± SE, and statistical significance was set at $p<0.05$.

RESULTS

Growth Performance and Yield of *Z. mays* Under Different Precipitation Patterns

Within AGRO, Table 2 shows no significant differences among rainfall treatments for any growth parameter namely leaf number, plant height, stem diameter and chlorophyll (SPAD), were statistically similar across T1–T3. However, there were differences in the number of kernels, and kernel yield (fresh and dry). Fresh weight was significantly higher under T2 (1233.30±72.23 g), closely followed by T3 (1216.70±71.73 g), while T1 had the lower fresh weight (970.00±71.24 g).

Table 2. Effect of precipitation and agroforestry integration on growth and yield of *Zea mays* (mean ± SE; n = 4 per treatment)

Growth Parameter *Zea mays* (AGRO)									
Treatment	Number of Leaves	Height (cm)	Diameter (mm)	Chlorophyll content (SPAD)	Fresh weight (Kg)	Dry weight (Kg)	Number of kernels	Kernel fresh weight (g)	Kernel dry weight (g)
T1	13.00^{A}	190.08^{A}	13.320^{A}	27.33^{A}	970.0^{A}	254.10^{A}	100.05^{B}	16.69^{B}	12.45^{C}
T2	13.00^{A}	187.33^{A}	13.743^{A}	28.80^{A}	1233.3^{A}	291.23^{A}	147.83^{A}	37.49^{A}	31.46^{A}
T3	12.50^{A}	180.70^{A}	13.753^{A}	32.20^{A}	1216.7^{A}	286.40^{A}	146.50^{A}	38.35^{A}	29.34^{B}
Growth Parameter *Zea mays* (NON-AGRO)									
Treatment	Number of Leaves	Height (cm)	Diameter (mm)	Chlorophyll content (SPAD)	Fresh weight (Kg)	Dry weight (Kg)	Number of kernels	Kernel fresh weight (g)	Kernel dry weight (g)
T1	12.50^{A}	179.62^{A}	13.40^{A}	19.867^{A}	887.50^{A}	170.39^{B}	119.0^{A}	36.34^{A}	26.56^{A}
T2	13.25^{A}	182.62^{A}	15.06^{A}	24.033^{A}	1037.50^{A}	234.14^{AB}	131.00^{A}	32.47^{B}	26.49^{A}
T3	13.25^{A}	182.95^{A}	14.26^{A}	23.533^{A}	987.50^{A}	246.00^{A}	120.0^{A}	32.63^{B}	25.92^{A}

Note: Different superscript letters within a column denote significant differences among rainfall treatments at $p<0.05$ (DMRT).

Significant differences were observed in the kernel-related parameters. The number of kernels differed significantly between treatments, with T2 recording the highest number (147.83±30.32 g), followed by T3 (146.50±20.65 g), while T1 recorded the lowest number (100.05±26.56 g). Kernel fresh weight was significantly higher in T2 (37.49±14.72 g) and T3 (38.35±12.34 g) than in T1 (16.69±10.89 g). Kernel dry weight also differed among treatments: T2 was highest (31.46±15.63 g), T3 was next (29.34±11.41 g), and T1 was lowest (12.45±6.31 g). These results indicate that normal (T2) and high (T3) rainfall improved kernel yield parameters, whereas low rainfall (T1) led to significantly lower kernel number and kernel weight.

Table 2 for the growth parameters of *Z. mays* (NON-AGRO) shows that similar trends were observed for the growth parameters. The number of leaves, plant height and chlorophyll content (SPAD) showed no significant differences between treatments. However, significant differences were observed in dry weight. Treatment T3 had the highest dry weight (246.00±25.44 g), followed by T2 (234.14±29.37 g), while T1 had a significantly lower dry weight (170.39±31.65 g). In contrast, the fresh weight did not differ for all treatments.

Kernel-related parameters in the NON-AGRO showed slight fluctuations. The number of kernels showed no significant differences between the treatments. However, kernel fresh weight significantly, with T1 having the highest value (36.34±2.64 g), while T2 (32.47±4.16 g) and T3 (32.63±2.44 g) were significantly lower. Kernel dry weight, with all treatments showing similar values.

When comparing AGRO and NON-AGRO at different precipitation levels, the AGRO system performed better at normal (T2) and high (T3) precipitation levels. Number of kernels, kernel fresh weight and kernel dry weight were higher in the AGRO system compared to the NON-AGRO system at T2 and T3. Conversely, at low rainfall (T1), the NON-AGRO outperformed the AGRO in kernel fresh weight with 36.34 g compared to 16.69 g in the AGRO system. However, the total dry weight of the plants remained lower in the NON-AGRO system under T1 compared to T2 and T3. These results suggest that the integration of *N. cadamba* into the AGRO system improves the performance and yield of *Z. mays* under normal and high rainfall conditions. At low rainfall, competition for resources in the AGRO system may have reduced yield performance.

The AGRO system showed better kernel yield parameters at T2 and T3, while the NON-AGRO system showed better kernel fresh weight at T1. These results emphasise the importance of rainfall patterns in determining the results of agroforestry integration on crop performance and yield.

Comparative Analysis of Growth and Yield Parameters of *Zea mays* Under Agroforestry and Non-Agroforestry Systems

Leaf number did not differ significantly between systems: AGRO, 12.83 ± 0.28 leaves; NON-AGRO, 13.00±0.43 leaves (p = 0.60). Stem diameter was also similar: AGRO, 13.60±0.24 mm; NON-AGRO, 14.23±0.83 mm (p = 0.27) (Table 3). These results indicate that the integration of agroforestry had no significant effect on the leaf number or stem diameter of *Z. mays* compared to monocropping.

Table 3. The effect of integration of *Neolamarckia cadamba* on growth performance and yield of *Zea mays*

Growth Performance						
Variable	*N. cadamba* x *Z. mays* (AGRO)	Only *Z. mays* (NON-AGRO)	n	t-value	dF	p
Number of leaves	12.83±0.28	13.00±0.43	3	-0.55	4	0.6087
Height (cm)	186.03±4.81	181.73±1.83	3	1.44	4	0.2221
Diameter (mm)	13.60±0.24	14.23±0.83	3	-1.28	4	0.2709
Chlorophyll content (SPAD)	29.44±1.44	22.47±2.31	3	2.74	4	0.0263
Fresh weight (g)	1109.2±71.82	970.83±76.37	3	2.29	4	0.0843
Dry Weight (g)	277.24±11.65	216.84±23.47	3	2.59	4	0.0452
Number of kernels	131.46±27.20	123.33±6.65	3	0.50	4	0.6418
Kernel fresh weight (g)	30.85±12.26	33.81±2.18	3	-0.41	4	0.7011
Kernel dry weight (g)	24.42±10.41	26.33±0.34	3	-0.32	4	0.7672

Note: Significantly different were detected at p<0.05 with (n = 4) using unpaired t-test

Chlorophyll content (SPAD) showed a significant difference between the two systems. AGRO cultivation recorded a significantly higher SPAD value of 29.44±1.44 compared to 22.47±2.31 in NON-AGRO cultivation (p = 0.0263). This result suggests that the integration of agroforestry positively influenced chlorophyll content, indicating an improved photosynthetic capacity of *Z. mays* in AGRO. No significant difference was observed in fresh weight between the two systems, where 1140±71.82 g) was recorded in AGRO compared to NON-AGRO (970.83±76.37 g) (p = 0.08). However, dry weight showed a significant difference between the systems, with AGRO having a higher mean value of 277.24±11.65 g compared to 216.84±23.47 g for NON-AGRO (p = 0.0452). This result indicates that the AGRO system improved biomass accumulation in *Z. mays*.

The number of kernels did not differ significantly between the systems, with AGRO having 131.46±27.20 kernels and NON-AGRO having 123.33±6.65 kernels (p = 0.64). Similarly, no significant difference was found kernel dry weight of the kernels, with values of 24.42±10.41 g for AGRO and 26.33±0.34 g for NON-AGRO (P = 0.76). These results indicate that kernel yield parameters did not differ significantly between AGRO and NON-AGRO.

Unpaired t-test analysis revealed that the AGRO system significantly improved the chlorophyll content (SPAD) and dry weight of *Z. mays* compared to the NON-AGRO system, while other growth and yield parameters, including the number of leaves, diameter, fresh weight and kernel-related variables, showed no significant differences.

DISCUSSION

The study found no significant differences in growth parameters, such as the number of leaves, plant height and stem diameter, between agroforestry (AGRO) and non-agroforestry (NON-AGRO). These observations are consistent with the results of Wamalwa *et al*. (2021), who reported similar growth responses in intercropped agroforestry trees, due to the minimal influence of light competition in the early growth stages. However, chlorophyll content (SPAD) was significantly higher in AGRO than in NON-AGRO ($p = 0.0263$). The higher SPAD under AGRO conditions may be attributed to the improved microclimatic conditions, including lower temperature stress and higher humidity favoured by the tree canopy. Similar patterns can be seen in maize alleys or border systems. Shade lowers the temperature of the canopy and the vapor pressure deficit. Litter improves infiltration and surface moisture. These benefits predominate in normal to wet seasons. In dry seasons, root competition can outweigh them, which explains the negative response under T1. This observation is supported by studies emphasising the role of agroforestry in enhancing photosynthetic capacity through a temperate microclimate and improved nutrient cycling (Mishra *et al*., 2021).

A significant difference was also observed in plant biomass where dry weight of *Z. mays* was significantly higher in AGRO (277.24±11.65 g) than in NON-AGRO (216.84±23.47 g) ($p = 0.0409$). This result suggests that the presence of *N. cadamba* may have positively influenced nutrient availability through litter decomposition and nutrient cycling, which is a widely recognised advantage of agroforestry systems (Froufe *et al*., 2020). While fresh weight had a higher mean value in the AGRO system, the difference was not statistically significant. Comparable results were reported by Dilla *et al*. (2018), where maize grown in agroforestry systems had higher biomass due to improved soil moisture and nutrient availability.

Kernel yield parameters gave contrasting results under different systems and rainfall conditions. In AGRO, number of kernels, fresh weight and dry weight were significantly increased under normal (T2) and high rainfall conditions (T3). This indicates that the AGRO system promotes kernel production under favourable moisture conditions, which is likely due to improved soil properties such as water retention and organic matter content, which are typical benefits of agroforestry systems (Ngaba *et al*., 2023). Conversely, the NON-AGRO performed better than the AGRO in kernel fresh seed weight under low rainfall (T1). This result may be attributed to competition for water and nutrients between *Neolamarckia cadamba* and *Z. mays* under drought stress, as competition between trees and plants can be pronounced under water-limited conditions (Khatta *et al*., 2023). Increasing the distance between *N. cadamba* and *Z. mays* can reduce below-ground competition. Light pruning during dry periods can reduce the trees' water consumption. Mulch helps to retain moisture in the soil. A small, targeted irrigation at the time of harvest and grain filling ensures yield with minimal water consumption. If water is very scarce, NON-AGRO or temporary irrigation in AGRO is advisable.

The significantly higher chlorophyll content and dry weight observed in the AGRO system are consistent with the concept that agroforestry can improve plant resilience and resource utilisation efficiency under normal and high rainfall conditions. Fahad *et al*. (2022) emphasised that trees integrated into agroforestry systems improve below-ground soil properties, such as nitrogen availability and organic carbon content, which can have a positive effect on plant growth. Under low rainfall (T1), the reduction in kernel yield in AGRO is consistent with evidence that water competition can outweigh microclimate benefits in tree crop systems during dry periods; mitigation through wider spacing, crown/pruning management, and small, well-timed irrigation is recommended (Kumar *et al*., 2022).

The implications of these results are important for the management of agroforestry systems under different rainfall conditions. Under normal and high rainfall conditions, the integration of *N. cadamba* with *Z. mays* improves the overall growth and yield performance. This result demonstrates the potential of agroforestry to optimise agricultural productivity while contributing to ecosystem services such as improved soil health and climate resilience (Jose, 2009; Wamalwa *et al*., 2021). However, under low rainfall conditions, monocultures can provide better yield performance due to less competition for water resources. This highlights the importance of selecting appropriate agroforestry species and optimising management practices such as pruning and irrigation to minimise resource competition under drought stress (Bayala & Prieto, 2020)

The AGRO system improved the chlorophyll content and dry weight of *Z. mays* under favourable rainfall conditions, demonstrating the benefits of integrating *N. cadamba*. However, under water-limited conditions, the NON-AGRO system outperformed the AGRO system in kernel fresh weight. This emphasises the need for adaptive management strategies in agroforestry systems to improve resilience under changing environmental conditions.

This study used one soil (Nyalau; *Typic paleudults*), one site, and one season. Pots can restrict roots and alter lateral interactions. Tree age and spacing did not vary. We did not test fertiliser–water interactions. These constraints limit broad generalisation. Future work should include field plots across seasons, more soils, and a spacing–age gradient.

CONCLUSION

This study shows that the integration of *Neolamarckia cadamba* with *Zea mays* improves chlorophyll, biomass, and yield under normal and high rainfall, while low rainfall can shift the balance in favor of belowground competition. The results support agroforestry as a practical option under weather variability, with clear limits under drought. For farmers, the best use case is edge or alley cropping in normally wet seasons; in dry conditions, maintain wider spacing, retain mulch, and apply small, well-timed irrigation during whorls and grain fill. Policy makers should include maize–kelampayan designs in extension and consider establishment support and simple irrigation measures as part of climate-smart agriculture. Future research should test the effects of spacing and tree age across multiple seasons and soils, measure water balance and microclimate, and assess costs and returns to smallholder farmers. Practical recommendation such as introduces integration of maize and kelampayan when rainfall is normal or high could be switch to wider spacing plus mulch and targeted irrigation when rainfall is low.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Universiti Malaysia Sarawak (UNIMAS) for financial support through the Shell Chair Grant Scheme (UNI/F07/SHC/83916/2023). We thank the Agrotechnology technical staff for their assistance with plant husbandry, irrigation set-up, and sample analyses, and the students (Jacklin Mathew and Vanishri A/P Kaly Sitthan) who helped with pot preparation and data collection.

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