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(RESEARCH ARTICLE)

Evaluation of broccoli (*Brassica oleracea* var. *italica*) response to nitrogen fertilizer under two different shaded conditions

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Abstract

Broccoli (*Brassica oleracea* var. *italica*) is a cruciferous vegetable gaining popularity for its taste and health benefits. This flowering head vegetable, related to cabbage and cauliflower, is a rich source of vitamins, minerals, and fiber. This versatile vegetable can be enjoyed raw, cooked, or roasted, making it a delicious and nutritious addition to any diet. Broccoli production is on the rise in Guyana and this project seeks to investigate the various effects that nitrogen fertilizer and shade has on the vegetative growth and yield of broccoli. Commencing, the broccoli seedlings were germinated and all the plots were prepared. Plot management was done where weed and pest and disease management was done. A soil test revealed the pH to be between 6-6.5 and the salinity to be 0.75-0.9 decisemens per centimeter. The drip irrigation system was also set up to supply the plants with adequate water. During the management of this research, prophylactic measures were implemented with the use of Caprid and Carbenazim to control insects and fungi respectively. The Split Plot Experimental Design was used where the main plots were the conventional shade house and the tunnel house and the sub plots were the five (5) different rates of nitrogen fertilizer (0, 75, 120, 180 and 225 kg N/ha). Urea was used as the nitrogen fertilizer. This study investigated the effects of nitrogen fertilizer and shade on the vegetative growth (average leaf length in centimeters and plant height in centimeters) and yield (number of curds per plant and total weight of curds per plant per treatment in grams). The data were collected and analyzed after which the results were thoroughly discussed. The results revealed that both nitrogen and shade had significant effects on the vegetative growth and yield of broccoli. Increasing the nitrogen application rate increased the vegetative growth as well as the yield of the broccoli. The tunnel house offering more light and better humidity and temperature control saw significantly greater result compared to the conventional shade house. Shade had significant differences in all the parameters of interest whilst nitrogen application rate had significant differences in all the parameters expect number of curds per plant. Tunnel houses, with their controlled environment promoting optimal light, temperature, and humidity, is significantly more favorable for broccoli growth compared to traditional methods. Additionally, while the study suggests that maximum yield was attained at 225 kg N/ha which is the highest rate, future research can be done to find the rate at which maximum yield is attained.

Keywords: Broccoli; Nitrogen Fertilizer; Shade House; Tunnel House; Yield; Growth; Guyana

1. Introduction

Broccoli (*Brassica oleracea* var. *italica*) is a cool-season vegetable that has captured the hearts (and stomachs) of health-conscious consumers worldwide [2, 3, 4, 11]. Prized for its large, tightly packed clusters of vibrant green flower buds, broccoli offers not only a delightful taste experience but also a concentrated package of essential nutrients [2, 3]. From vitamin C and K to fiber and folate, broccoli boasts an impressive nutritional profile, making it a valuable addition to any healthy diet [2, 4]. Interestingly, broccoli shares its ancestry with other cool-weather favorites like kale, cabbage, and cauliflower [2]. All these cruciferous vegetables trace their roots back to the eastern Mediterranean region, where

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they were first cultivated [2, 11]. While the exact date of domestication remains a topic of debate among historians, evidence suggests cultivation of sprouting broccoli began in Italy, eventually reaching the shores of England and America in the late 1700s [2, 3, 11].

Among the essential elements for plant health, nitrogen reigns supreme as the indispensable fuel [1, 4]. Plants readily utilize nitrogen in the form of nitrate (NO_3^-) and ammonium (NH_4^+) [5, 6]. This critical nutrient acts as a powerful growth engine, significantly boosting plant development, yield, and overall quality [8, 10]. Nitrogen's influence extends far beyond mere size; it plays a vital role in various biochemical and physiological processes within the plant [14]. One of its most crucial functions lies in the production of chlorophyll, the pigment that enables plants to capture sunlight and convert it into usable energy through the remarkable process of photosynthesis [1, 4, 5]. Essentially, nitrogen serves as the foundation for the entire food chain, as it empowers plants to capture solar energy and transform it into the building blocks of life [6, 8, 10]. Additionally, nitrogen forms the backbone of energy-transferring molecules like ATP (adenosine triphosphate), allowing plant cells to efficiently utilize the energy released during metabolism [10, 14]. Finally, nitrogen is a fundamental component of DNA, the genetic blueprint that guides cell growth, reproduction, and ultimately, the development of the entire plant [1, 4, 5, 6, 8, 10, 14].

The 2022 CARICOM Intersessional Meeting report served as a wake-up call, highlighting broccoli and cauliflower as high-value commodities heavily reliant on import within the region [2, 7]. This insight ignited a spark within the Guyanese government, prompting them to focus on promoting domestic broccoli cultivation [7]. As a result, broccoli production has seen a steady rise among Guyanese farmers, eager to tap into this exciting new market opportunity [7]. However, with this burgeoning demand comes the crucial need for effective and sustainable management practices to ensure long-term success for Guyanese broccoli growers [7].

Unfortunately, a significant challenge currently hinders the full potential of Guyanese broccoli production: the paucity of readily available information on best management practices. This lack of knowledge creates a roadblock for farmers, preventing them from maximizing their production potential and achieving optimal crop yields. Therefore, it becomes crucial to conduct research and experimentation swiftly and meticulously. By bridging this knowledge gap, we can empower Guyanese farmers to flourish in the burgeoning broccoli market, ensuring the long-term viability and sustainability of this exciting new agricultural endeavor in Guyana.

The general objective of this study is to determine the effects of varying rates of nitrogen fertilizer as well as varying shaded conditions on the performance of broccoli. The specific objectives that guide this study are: (1) To investigate the effects of nitrogen fertilizer applied at different rates on the vegetative growth of broccoli under different shaded conditions. (2) To investigate the effects of nitrogen fertilizer applied at different rates on the yield of broccoli under different shaded conditions. (3) To investigate the effects of the different shaded conditions on the vegetative growth of broccoli when nitrogen is applied at varying rates. (4) To investigate the effects of the different shaded conditions on the yield of broccoli when nitrogen is applied at varying rates.

2. Method

2.1. Study location

This study was conducted at the University of Guyana, Berbice Campus, John's Science Center, Corentyne, Berbice under Shade House and Tunnel House.

2.2. Experimental design

This study utilized a split-plot design to investigate the interaction between shade environment and nitrogen application rates on broccoli growth. The main plots consisted of two different shade structures: a tunnel house and a conventional shade house. These shade houses likely create to distinct micro climates with varying light intensity, humidity and temperature. Within each of these main plots, five subplots were established. Each subplot received a different treatment of nitrogen fertilizer, applied in the form of urea (containing approximately 46% nitrogen). This allows researchers to assess the independent and combined effects of shade environment and nitrogen availability on broccoli performance.

2.3. Description of main plot

Shade house 1 is a conventional shade house which is made of plastic and shade net. Shade house 2 is a tunnel house made of plastic only.

2.4. Soil type

Both shade houses consisted of the same potting medium which is Ithica Sandy Loam, paddy hulls and cow manure.

2.5. Description of subplot

Table 1 Different Application Rates of Nitrogen Fertilizer

Treatments	Rates
T1	0 kg/ha (Control)
T2	75 kg/ ha
T3	120 kg/ ha
T4	180 kg/ ha
T5	225 kg/ ha

Each treatment was replicated three times and each replicate will contain six plants.

2.6. Experimental management

- Plot size, irrigation system and broccoli cultivar were identified. The F1 Green Tropic Variety was used whilst the type of irrigation used was drip irrigation because it helps to reduce water loss due to evaporation and helps to reduce diseases. However, due to the high temperature, the plants were manually watered for the first 5 weeks using a water can.
- Both plots (main plots and subplots) were prepared. A fork was used to upturn the land after which a mechanical tiller was used to break up the soil and make it loose.
- Soil samples were taken randomly from each experimental plot at depth of zero to six inches and pH and salinity test was done. The results showed favorable conditions for both; pH was between 6-6.5 and salinity was 0.75-0.94 decisemens per centimeter.
- Throughout the experiment, researchers monitored the microclimate within the shade houses using a hydrometer and thermometer, tracking temperature and humidity fluctuations.
- Additionally, a Pre-inspection of the fields identified any potential insect pests. To prevent weed competition, a Pre-emergence herbicide (Lazio) was applied before planting the broccoli.
- Pre-germination of broccoli seedlings was done and four weeks after germination, seedlings were transplanted into the prepared plots, with each subplot receiving six healthy seedlings per replicate.
- To ensure precise application, nitrogen fertilizer (urea) was pre-weighed a day before treatment and applied to the plants two weeks after transplanting.
- In addition to the core treatments, the experiment employed several standard practices to optimize plant growth and data collection. A basal application of phosphorus (P2O5) at 50 kg/ha and potassium (K2O) at 160 kg/ha was provided at the same time as the initial nitrogen application to ensure balanced nutrient availability.
- A preventative pest and disease management program was implemented using caprid and big ben (carbenazim) following label instructions. This application aimed to minimize pest and disease pressures without compromising the integrity of the experiment.
- To ensure consistent moisture levels and promote optimal growth, the broccoli plants were irrigated daily. Weed management was conducted manually to prevent competition for resources.
- Data collection focused on the five key parameters established for the experiment. Following data collection, researchers meticulously analyzed the results to identify any significant interactions between shade environment, nitrogen application rates, and the chosen parameters.
- The findings from the experiment, including data analysis and interpretations, were compiled into a comprehensive report. This report serves as a valuable resource for understanding the influence of shade and nitrogen management on broccoli production under controlled environments.

2.7. Parameters of interest

2.7.1. Vegetative growth parameters

- Height of Broccoli Plant (cm) at Maturity

At the time of maturity (85 days after transplanting), the height of the broccoli plant was taken from the base of the stem to the tip of the crown.

- Average leaf length (cm) at maturity

Leaves were gently taken off from the stem and were measured from the base of the stalk to the petiole to the apex.

- Days to 50% flowering.

This data was taken when three (3) of the six (6) plants in each treatment achieved. The number of days the broccoli plants took to achieve this was recorded. When this research was done, this parameter was removed because of insufficient data to analyze.

2.7.2. Yield parameters

- Number of Curds per plant

This data was gathered when the plants were harvested, with a curd being defined as a cluster of green buds coming together to form the head with all resting on a thick stem.

- Total Weight of Curds per plant/ treatment (g).

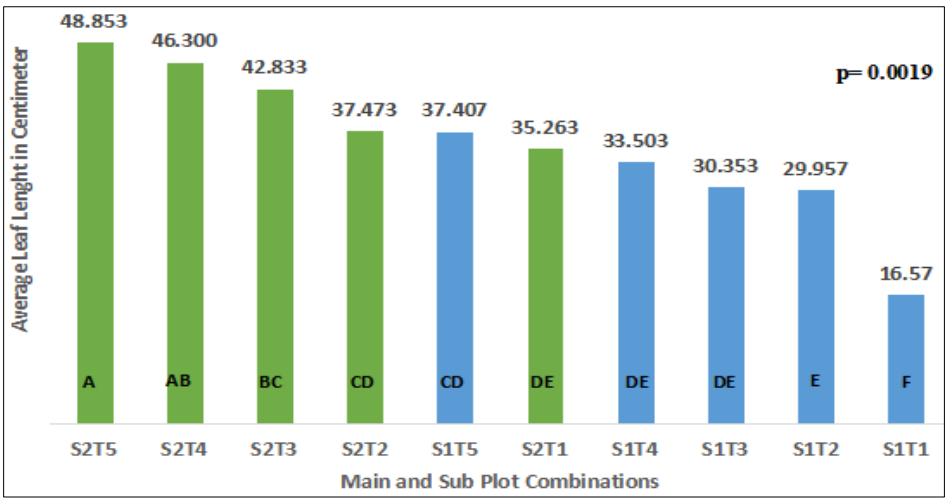
This data was gathered at harvesting and it was collected with each plants having their heads weighed and recorded. The head was placed into labeled paper bags weighed using a digital scale.

2.8. Statistical analyses

The data collected was analyzed using the STASTIX 10 program. Data for each parameter were subjected to analysis of variance (ANOVA) to determine whether there are differences among the treatments and less significant difference (LSD) was used to determine if there are significant differences among treatment means. Microsoft Word and Microsoft Excel were used to create all graphs and tables.

3. Result and Discussion

3.1. Parameter 1: Average leaf size



Key: Blue Bars-Shade House 1, Green Bars-Shade House 2

Figure 1 Average leaf length in centimeter

Figure 1 above depicts the average leaf length across various combinations of shade house type (S) and nitrogen application rate (T). Plants grown shade house 2 had the highest nitrogen application (S2T5, 225 kg/ha) exhibited the longest average leaves (48.853 cm), group (A) compared to all others. This finding suggests a potential positive

correlation between higher nitrogen application and increased leaf length within a controlled tunnel environment. Conversely, plants in the shade house 1 had no nitrogen added (S1T1) had the shortest leaves (16.57), forming their own distinct group (F). This suggests that there are significant differences in leaf length between the two groups since the analysis employed an alpha level of 0.05 with the p value being 0.0019.

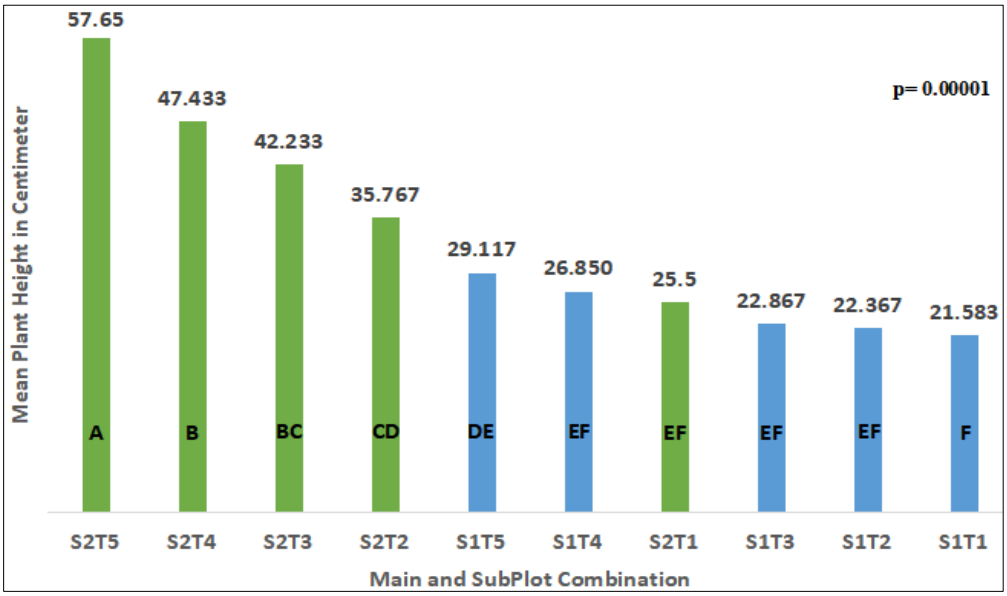
As the nitrogen application rate increased, so did the average leaf length within both shade house types. This suggests a dose-dependent effect of nitrogen on leaf growth. Shade also played a crucial factor as plants in the tunnel house with the shade plastic only, exhibited greater leaf growth with an average of 42.144 cm whilst the conventional shade house with the shade plastic and the shade net, showed an average leaf growth of 29.558 cm.

Further, when comparing the two intermediate application rates (120 kg/ha and 180 kg/ha) across both shade houses, the higher rate (180 kg/ha) consistently produced longer leaves. For Shade house 1 (Conventional Shade house), 120 kg N/ha saw 30.353 cm whilst 180 kg N/ha saw 33. 503 cm. Shade house 2 (Tunnel house) saw 120 kg N/ha having 42.833 cm and 180 kg N/ha having 46.300 cm. This finding aligns with the observations reported by Haque *et al*. (1996) [5], who also found that 180 kg/ha of nitrogen fertilizer resulted in better broccoli growth.

Metwaly (2016) [6] highlights, nitrogen as a vital component of many plant structures, including chlorophyll, proteins, enzymes, and cell walls. These elements play a fundamental role in overall plant growth and function. Metwaly's research suggests that nitrogen fertilizer can promote leaf expansion and elongation by influencing cell division and cell size [6]. While this mechanism provides a potential explanation for our findings, our study provides strong evidence that increasing nitrogen application rates can indeed lead to a significant increase in average leaf length in broccoli. Sunlight can also be deemed as a crucial factor as plants in the tunnel house without the shade net saw better leaf growth than plants under the conventional shade house.

These results offer valuable insights into the complex interplay between shade house type and nitrogen application rates in influencing broccoli leaf length. This knowledge can potentially lead to improved crop yields and overall plant health, contributing to a more sustainable and productive agricultural industry.

3.2. Parameter 2: Plant height



Key: Blue Bars-Shade House 1, Green Bars-Shade House 2

Figure 2 Plant height in centimeter

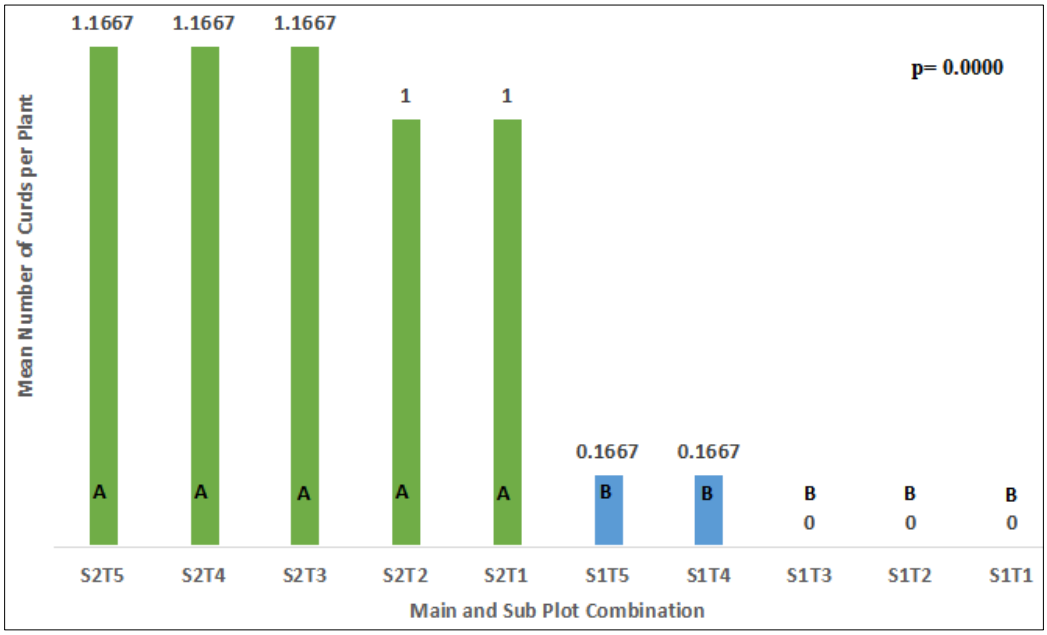
Figure 2 categorizes different combinations of shade house type (S) and nitrogen application rate (T) based on their average plant heights. The results reveal a clear trend. S2T5, representing the shade house 2 with the highest nitrogen application (225 kg/ha), had the tallest plants with an average height of 57.65 cm, forming group (A) significantly different from all others. Conversely, S1T1, representing the shade house 2 with no nitrogen added, had the shortest plants (21.583 cm) and formed its own group (F), also significantly different from all others. This suggests that there are significant differences in plant height between them since the analysis employed an alpha level of 0.05 with the p value being 0.00001.

Additionally, trends were observed when the nitrogen application rate increased, so did the average plant height within both shade house types. This once again suggests a dose-dependent effect of nitrogen on plant height. Shade also played a crucial factor as plants in the tunnel house with the shade plastic only, displayed greater plant height with an average of 41.72 cm whilst the conventional shade house with the shade plastic and the shade net, exhibited an average plant height of 24.61 cm.

These findings support observations reported by Haque *et al.* in 1996 [5]. There were significant differences in plant height between the two intermediate nitrogen application rates (120 kg/ha and 180 kg/ha). Conventional shade house shows an average height of 22.867 cm for 120 kg/ha and 26.850 cm for 180 kg/ha. The tunnel house displayed a similar trend, with an average height of 42.233 cm for 120 kg/ha and 47.433 cm for 180 kg/ha.

Scientific literature provides a potential explanation for the observed relationship between nitrogen and plant height. Plett *et al.* (2020) [11] suggest that sufficient nitrogen promotes chlorophyll production, a key element in photosynthesis. Improved photosynthesis leads to increased sugar production, which the plant utilizes for energy and growth processes, leading to a taller plant and better growth [11]. Additionally, adequate nitrogen facilitates the uptake of other essential nutrients from the soil, further supporting overall plant development [11]. In this context, increasing the nitrogen application rate contributes to increased plant height by promoting these physiological processes.

3.3. Parameter 3: Number of curds



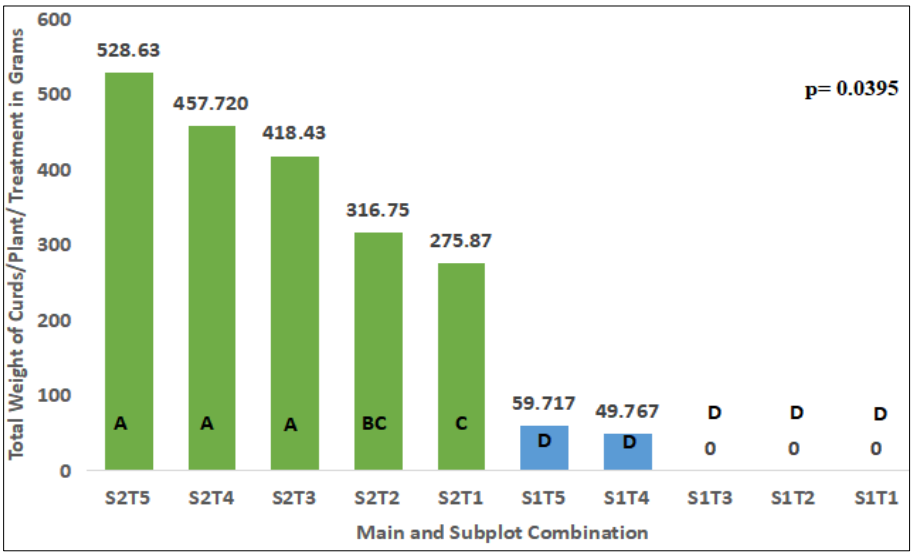
Key: Blue Bars-Shade House 1, Green Bars-Shade House 2

Figure 3 Number of curds per plant

Figure 3 shows number of curds per plant. Treatments T1, T2, T3, T4, and T5 in S2 all have a mean of 1.0000 or 1.1667 and are assigned to group A. This suggests that the different treatments (T1-T5) have no effect on the number of broccoli curds per plant within shade house S2. All treatments (T1-T5) in S1 have a mean of 0.0000 and are assigned to group B. This indicates that the treatments also have no statistically significant effect within shade house S1, but the overall mean value in S1 (0.0000) is statistically different from the mean values in S2 (1.0000 or 1.1667). There is a clear difference in the mean outcome variable between the two shade house types (S1 and S2), regardless of the treatment applied. The values in S2 are consistently higher than those in S1.

These findings did not support observations reported in 1996 by Haque *et al*. [5]. There were significant differences in the number of curds per plant between the two intermediate nitrogen application rates (120 kg N/ha and 180 kg N/ha). However, within each shade house type, the difference in height between these two rates was not statistically significant. The data for the conventional shade house reveals an average number of curds of 1.1667 for 120 kg N/ha and same for 180 kg N/ha. The tunnel house displayed a different trend, with an average number of 0.1667 curds for 120 kg N/ha and 0 curds for 180 kg N/ha. Whilst a high rate of nitrogen is ideal for good growth, exposure to sunlight very important for growth of broccoli.

3.4. Parameter 4: Total weight of curds



Key: Blue Bars-Shade House 1, Green Bars-Shade House 2

Figure 4 Total Weight of curds per plant per treatment in grams

There's a clear and substantial difference in yield between the two shade house types (S1 and S2). Across all treatments (T1-T5), yields in S2 are consistently much higher than those in S1. This suggests that the shade house environment in S2 is significantly more favorable for crop growth. The much lower yields in S1 compared to S2 could be due to various factors such as less sunlight penetration and different temperature or humidity control. A trend observed was as the nitrogen application rate increased, so did the number of curds per plant per treatment within both shade house types. This suggests a dose-dependent effect of nitrogen on the number of curds per plant per treatment. Shade also played a crucial factor as plants in the tunnel house with the shade plastic only, exhibited greater plant height with an average of 399.48 grams whilst the conventional shade house with the shade plastic and the shade net, showed an average curd weight per plant per treatment as 54.72 grams with only two set treatments showing curds as the maturity stage was reached.

When these results were compared to the findings and observations reported by Haque *et al*. in 1996 [5], their research stated that there were significant differences in curd weight between the two intermediate nitrogen application rates (120 kg/ha and 180 kg/ha). However, within each shade house type, the difference in weight between these two rates was not statistically significant. The data for the conventional shade house shows did not show any curds for 120 kg/ha and 49.767 grams for 180 kg N/ha. The tunnel house displayed a better trend with an increase in curd weight, with an average height of 418.43 grams for 120 kg N/ha and 547.720 grams for 180 kg N/ha.

3.5. Agro-environmental and nutrient management strategies for optimizing broccoli cultivation in tropical and subtropical climates

The comparative analysis of these studies offers a multidimensional understanding of agronomic strategies to optimize broccoli cultivation across diverse agro ecological regions, particularly in thermally stressful and nutrient-variable environments. These findings are especially relevant to tropical countries such as Guyana, where climatic and soil conditions pose unique challenges for the successful production of cool-season crops like broccoli.

3.5.1. Climate manipulation and microclimate optimization

Getachew *et al*. (2016) [3] in Western Ethiopia and Nooprom *et al*. (2013) [9] in Thailand both investigated the role of climatic factors, namely, temperature and light exposure, in determining the performance of broccoli crops. Getachew *et al*. [3] focused on the effect of planting dates with different nocturnal temperatures, revealing significantly better performance during cooler months [3]. This underscores broccoli's thermo-sensitivity and supports the conclusion that night temperature is a critical determinant of vegetative and reproductive growth. In contrast, Nooprom *et al*. [9] emphasized artificial manipulation of the microclimate through shading, which reduced heat stress by moderating light intensity and temperature while increasing relative humidity [9]. Both studies converge on the idea that mitigating thermal stress, whether temporally through planting schedules or physically via shading, enhances broccoli growth and yield. This is of direct relevance to Guyanese agriculture, where high nocturnal temperatures and intense solar radiation

can impede broccoli cultivation. These findings suggest that a dual strategy combining optimal planting windows and shading structures could be highly effective under tropical conditions.

3.5.2. Macronutrient management: nitrogen, phosphorus, and potassium

The centrality of nutrient management to broccoli productivity was explored in several geographically and methodologically diverse studies. Yoldas *et al*. (2008) [14] demonstrated a direct and positive linear relationship between increasing nitrogen application and broccoli yield in Izmir, Turkey [14]. This trend was corroborated by Giri *et al*. (2013) [4] in Nepal, whose varietal comparison also implied that the optimal nitrogen level may exceed 200 kg/ha for maximal productivity [4]. Complementarily, Haque *et al*. (1996) [5] in Bangladesh provided experimental validation for the effectiveness of higher nitrogen rates (180 kg N/ha) in enhancing curd yield, plant height, and leaf number, thus reinforcing nitrogen's role in both vegetative and reproductive parameters [5]. Collectively, these studies establish nitrogen as a critical yield-limiting factor in broccoli production and highlight the necessity for region-specific optimization.

In addition to nitrogen, phosphorus and potassium have also been recognized as pivotal. Uddain *et al*. (2006) [13] conducted a focused assessment of phosphorus application in Bangladesh, identifying 50 kg P/ha as the optimal dose for maximizing floret yield [13]. Unlike nitrogen, whose effects were dose-dependent across a broader range, phosphorus demonstrated a peak response at a specific application rate, suggesting a more defined physiological threshold beyond which yield benefits plateau or decline. In Brazil, DaSilva *et al*. (2010) [2] elucidated the significance of potassium by demonstrating that 160 kg K/ha maximized uptake and supported crucial physiological functions, including enzymatic activity and stress tolerance [2]. This finding aligns with the broader understanding of potassium's role in enhancing plant resilience and metabolic efficiency.

3.5.3. Synthesis and implications for Guyanese agriculture

Synthesizing the findings across these studies reveals a layered strategy for optimizing broccoli cultivation in tropical and subtropical climates. Climatic adaptations (e.g., adjusted planting schedules and artificial shading) serve as the first line of defense against abiotic stress, particularly temperature extremes, which can severely limit broccoli productivity [7]. Complementing these measures, tailored macronutrient management especially nitrogen, phosphorus, and potassium ensures that physiological and morphological development is not constrained by nutritional deficiencies [7].

For Guyanese farmers, these insights underscore the need for an integrated crop management approach that combines both climate-sensitive practices and site-specific fertilization regimes. Future research should prioritize agro ecological trials within Guyana to validate these externally derived findings under local conditions, considering varietal responses, soil nutrient dynamics, and socioeconomic feasibility. Such efforts would enhance the resilience and profitability of broccoli production, contributing to national food security and agricultural diversification in Guyana.

4. Conclusion

The findings of this study revealed that tunnel houses with plastic roofs allowing sunlight penetration are significantly more favorable for broccoli growth and development compared to conventional shade houses. This is likely due to factors like improved light availability, temperature, or humidity control within the tunnel house environment.

Consequently, the study indicates that the varying nitrogen fertilizer application rates also played a significant role in broccoli growth and yield. Increasing the application rate of nitrogen fertilizer leads to increased vegetative growth and yield, of broccoli and this can be seen with the highest rate performing best.

Tunnel houses, with their controlled environment promoting optimal light, temperature, and humidity, is significantly more favorable for broccoli growth compared to traditional methods. While the study suggests that maximum yield was attained at 225 kg N/ha which is the highest rate, future research should be conducted to find the rate at which maximum yield is attained.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors certify that this submission is original work and is not under review at any other publication. The authors hereby declare that this manuscript does not have any conflict of interest.

Disclosure of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Data Availability - Data will be made available on request.

Statement of informed consent

The authors declare that informed consent was obtained from all individual participants included in the study. All work utilized in this study was fully cited and referenced so authors of prior researches are given their due credentials for their work.

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