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RESEARCH ARTICLE

Effect of rate and split application of Albert's solution on growth and yield of cauliflower under protected house conditions in the Low Country Wet Zone of Sri Lanka

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Abstract: In response to challenges posed by unsustainable fertilizer practices, this study aimed to investigate the effects of fertilizer rate and split application on cauliflower growth and yield under protected house conditions. The cauliflower variety "White Flash" (*Brassica oleracea* var. botrytis) was grown in open-top grow bags with coconut coir potting media. Albert's solution (N: 10.6%, P: 9.3%, K: 16.3%, Ca: 11%, Mg: 2.25%) was used as fertilizer. Three fertilization rates (R1: 1.0, R2: 1.5, R3: 2.0 g/plant/day) and three split applications (S1: 1, S2: 2, S3: 3 splits/plant/day) were randomly allocated in a two-factor factorial completely randomized design, each with four replicates. The control group followed current farmer practices (R3S1) with daily treatment applications. The average temperature and relative humidity inside the protected house were 29℃ and 84%, respectively. Growth variables, including plant height and leaf number, were measured biweekly, and leaf area was measured at harvesting. Fresh plant weight, curd weight, and curd diameter were recorded at harvest to assess yield. The interaction between rate and split application significantly ($p<0.05$) affected cauliflower growth and yield. Among the treatments, significantly, the highest curd weight (490.95 g), curd diameter (13.8 cm), and harvest index (40.9%) were observed in the R2S3 treatment. This study concludes that a 1.5 g/plant/day fertilization rate with 3 split applications of Albert's solution is cost-effective and enhances cauliflower growth and yield under protected house conditions in Sri Lanka's Low Country Wet Zone.

Keywords: *Albert's solution, Cauliflower, Hydroponics, Nutrient management, Protected agriculture, Rate and split application of fertilizer*

Introduction

Rapid demographic growth puts global food security at risk by placing a strain on natural resources and various agricultural practices. This need frequently exceeds agricultural systems' capacity to provide food sustainably to meet the needs of an expanding population. According to the (FAO *et al.*, 2020), the global population is projected to reach 9.7 billion by 2050, further exacerbating these challenges. Furthermore, changes in land use, driven largely by population growth, particularly urbanization and deforestation, can reduce the availability of arable land and disrupt ecosystems vital to agriculture (Lal, 2015). These issues are made worse by climate change, which alters climatic trends and causes excessive climate events that lessen agricultural yield (Wheeler and von Braun, 2013, IPCC, 2018).

Therefore, to cope with demanding situations raised by population growth, climate change, and food insecurity, most agricultural nations are moving towards protected agriculture. According to (Kumara *et al.*, 2015), in Sri Lanka, protected farming is notably more prevalent in upcountry and mid-country regions than in the low country. With their higher elevations and milder temperatures, these areas provide optimal growing conditions for a diverse range of crops under

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protected conditions. Therefore, the popularization of protected farming is beneficial in the Low Country Wet Zone to reduce post-harvest losses, lower high transportation costs and decrease the distance from farm to fork.

Further, hydroponics or soilless cultures play a vital role in protected culture technology due to the elimination of soil and water-borne diseases. Among various hydroponic systems, aggregate hydroponic systems are more popular in the world under protected farming (Caintic and Salas, 2018). Coconut coir peat is the widely used growing substrate in aggregate hydroponic systems in Sri Lanka due to favorable characteristics such as optimum water holding capacity, lightweight, high porosity, and slightly acidic with high cation exchange capacity (Kumarasinghe *et al.*, 2016).

Moreover, high-value crops like bell pepper, cauliflower, tomato, and salad cucumber play a significant role in the protected agriculture sector. In the context of Sri Lanka, cauliflower (*Brassica oleracea* var. botrytis) is widely grown under controlled conditions with an optimum relative humidity of 60 - 70% and an optimum temperature of 21 – 28 °C (Mufeetha *et al.*, 2021).

Further, effective nutrient management is crucial for sustainable farming, particularly for crops with high demand, like cauliflower. According to Kahandage *et al.*, (2023), poor fertilizer application techniques have been connected to both environmental harm and decreased economic effectiveness in farming. Similar to this, Wijesekara and Marambe, (2011) pointed out that excessive fertilizer and water use in farming has become a popular practice to increase yields. However, this frequently results in nutrients being washed to deeper layers from the topsoil, decreasing the effectiveness of both water and nutrients.

As discussed by Ali Al Meselmani, (2022), growth and yield of containerized crops mainly depended on the rate of nutrient application in the delivered solution. But in Sri Lanka, a lot of negative consequences have occurred due to the inappropriate use of fertilizers for vegetable production, and it has obtained the growing attention of the scientific community. But still, crop-specific fertigation patterns under controlled conditions are lacking for high-value crops like cauliflower. For instance, splitting fertilizer treatments can serve as a beneficial strategy to enhance plant nutrient uptake Sajjad *et al.*, (2025). This method not only reduces the detrimental effects of chemical fertilizers on soil and water but also promotes healthier plant growth. Although some may dispute this approach, it is evident that a more nuanced application of fertilizers is essential because it strikes a balance between productivity and environmental sustainability.

Additionally, in a controlled environment, plant nutrition requirements are mainly supplied by inorganic fertilizers. According to (Ekanayake and Fernando, 2022), Albert's solution is considered the balanced fertilizer mixture for hydroponics. However, the growth and yield performances of cauliflower with rate and split application of Albert's solution are still not studied under protected house agriculture in the Low Country Wet Zone of Sri Lanka. To increase fertilizer usage efficiency and promote sustainable agricultural output, (Nakachew *et al.*, 2024) emphasized the necessity of investigating these approaches. Additionally, Dandeniya and Dharmakeerthi, (2020), pointed out that there is a substantial knowledge vacuum regarding cauliflower's performance in controlled agricultural systems because the majority of research on the crop has been in open-field settings.

Therefore, the proposed study would be significantly important for commercial protected house vegetable farming and induce positive socioeconomic and environmental impacts on the community. Therefore, the objectives of the study were to identify the optimum fertilization pattern on growth and yield performances of cauliflower under protected house conditions in Low Country Wet Zone of Sri Lanka.

Materials and Methods

A protected house (92.9 m^2) located at the Faculty of Agriculture, University of Ruhuna, Sri Lanka which is situated in the Low Country Wet Zone (WL2) was used for the experiment. The experiment was conducted from October 2021 to January 2022. During the research period, the average temperature and relative humidity were recorded as 29 °C and 84%, respectively, according to meteorological reports. An open-top vent type protected house with 1,000 gauges ploy film for the roof and insect-proof net (40 mesh) for the side walls were used to cover the protected house. A black and white double-sided polythene mulch (top layer - white color and bottom layer - black color) was used to cover the floor to reduce heat generation.

Cauliflower variety White Flash (F1 hybrid, *Brassica oleracea* var. botrytis) and open-top grow bags (23 x 20 x 23 cm^3) with coconut coir dust were used for the experiment. Growing bags were placed with 45 x 45 cm center-to-center spacing. Albert's solution was applied as the inorganic fertilizer solution. Department of Agriculture, Sri Lanka recommendations for cauliflower were followed (DOA, 2025) as crop management practices according to their growth stages. Seedlings were raised in a coir pellet nursery. After 28 days of the nursery period, uniform and vigorous seedlings were selected to transplant in open-top grow bags.

The treatment application started after 2 weeks of transplanting. The rate (R) and split (S) of fertilization were tested as the main factors. The fertilization rate had three levels, and the number of split applications was three, resulting in a total of nine treatment combinations (Table 1). The experimental design was a two-factor factorial completely randomized design with four replicates. R3S1, the existing farmers' practice was used as the control (Karunarathne *et al.*, 2022). The first split application was performed at 7.00 - 8.00 a.m., the second was done at 10.00 – 11.00 a.m., and the third split was applied at 1.00 – 2.00 p.m. However, at the end of the day, each plant received 200 mL of Albert's solution along with their defined fertilizer rate. Treatments were applied daily. A common irrigation schedule was practiced. At the end of the day, each plant received 800 ml of total water with three splits. Each plant received 300 ml of water from the first and second splits separately. At the last split, each plant received 200 ml of water. Also, common fungicide, insecticide, and other chemical application schedules were practiced as an initial prevention method for pests and diseases.

Table 1. Treatment combinations of the experiment

Main factors		Treatment combinations
Rate of fertilization (R) (g/plant/day)	Split of fertilization (S) (splits /day)	
R1 (1.0)	S1 (1)	R1S1–(T1)
	S2 (2)	R1S2–(T2)
	S3 (3)	R1S3–(T3)
R2 (1.5)	S1 (1)	R2S–(T4)
	S2 (2)	R2S2–(T5)
	S3 (3)	R2S3–(T6)
R3 (2.0)	S1 (1)	R3S1–(T7)
	S2 (2)	R3S2–(T8)
	S3 (3)	R3S3–(T9)

As growth parameters, plant height and number of leaves/plants were measured at two-week intervals for 8 weeks, and leaf area was measured at the harvesting. Plant height was measured vertically from the base of the plant to the apical bud. And number of leaves per plant was recorded by counting totally expanded leaves with a minimum length of 0.03 m in the cauliflower. Further at the harvesting 7th, 14th and 21st leaves were gained to measure the average leaf area per plant using a graphical method. As yield parameters, total fresh plant weight (with roots), fresh curd weight, and curd diameter were measured at the harvest. Finally, the harvest index was calculated using Equation 1 (Dhakal *et al.*, 2009).

$$\text{Harvest index} = \frac{\text{Economic yield (Curd yield)}}{\text{Total biological yield}} \text{ x } 100$$

…………………………………………...**Equation 1**

Statistical Analysis

Analysis of Variance (ANOVA) from the Statistical Analysis System (SAS) 9.1.3 version was used to analyze data statistically. The Duncan's New Multiple Range Test was then used to compare treatment mean differences at the 5% probability level.

Results and Discussion

The results showed a significant interaction ($p < 0.05$) between the rate and split application of Albert's solution on the growth and yield characteristics of cauliflower (except plant height) cultivated in Sri Lanka's Low Country Wet Zone under protected house conditions.

Plant height

However, as shown in Fig. 1 and 2, though there was no significant interaction ($p > 0.05$) between rate and split application of Albert's solution, both factors individually had a significant effect ($p < 0.05$) on enhancing plant height from the 2nd to the 8th week.

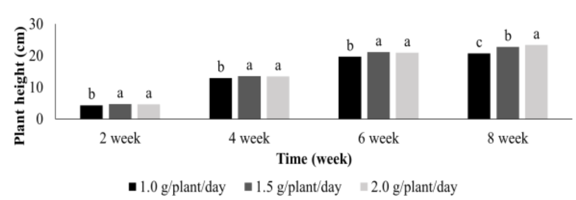

Figure 1. Effect of the rate of fertilization on plant height at different weeks after transplanting. Means presented in bars with different letters are statistically different from each other at 5% probability level as determined by DMRT.

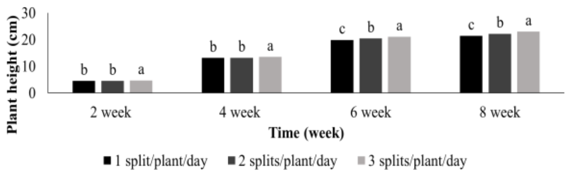

Figure 2. Effect of split of fertilization on plant height at different weeks after transplanting. Means presented in bars with different letters are statistically different from each other at 5% probability level as determined by DMRT

Number of leaves per plant

As shown in Fig. 3, R2S3 (1.5 g/plant/day with 3 splits) and R3S3 (2.0 g/plant/day with 3 splits) obtained significantly higher (p < 0.05) numbers of leaves per plant when compared with other treatments in the 2nd to 8th weeks after transplanting onwards except 6th week.

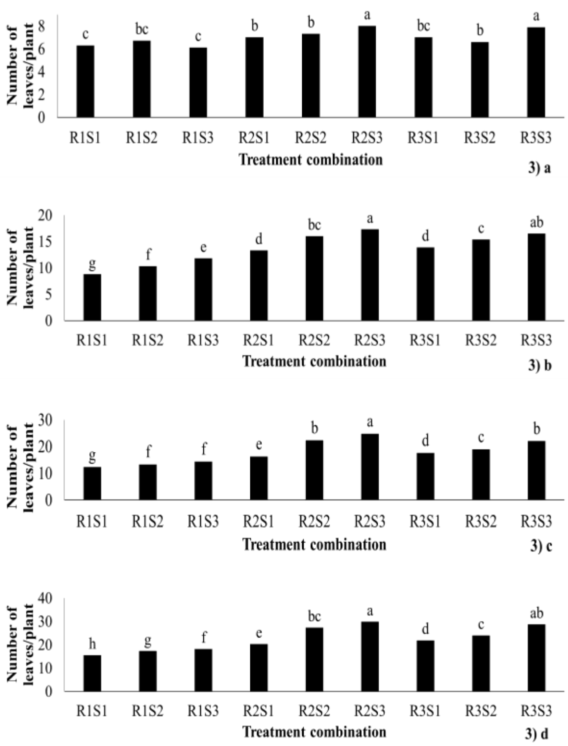

Figure 3. Effect of treatments on the number of leaves/plants at a) 2nd week b) 4th week, c) 6th week, and d) 8th week after transplanting. Means presented in bars with different letters are statistically different from each other at 5% probability level as determined by DMRT

In the 6th week after transplanting onwards, the number of leaves per plant was only significantly highest (p < 0.05) in the R2S3 (1.5 g/plant/day with 3 splits) treatment compared to other treatments (Fig. 3c). Further, significantly lower performances (p < 0.05) 2nd week to 8th week were obtained from R1S1 (1.0 g/plant/day with 1 split) compared to other treatments (Fig. 3).

Leaf area

According to Fig. 4, a significantly higher (p < 0.05) mean leaf area was recorded by R2S3 (1.5 g/plant/ day with 3 splits), and R3S3 (2.0 g/plant/day with 3 splits) treatments at the harvesting compared to other treatments. Same as number of leaves/plants, a significantly lower (p < 0.05) leaf area was obtained from R1S1 (1.0 g/plant/day with 1 split) treatment (Fig. 4).

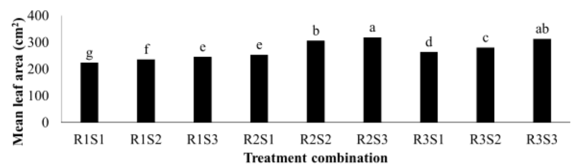

Figure 4. Effect of treatments on mean leaf area at harvesting (8th week after transplanting). Means presented in bars with different letters are statistically different from each other at 5% probability level as determined by DMRT

Effect of rate and split application of Albert's solution on the growth of cauliflower

The rate and split application of fertilizers have a significant impact on cauliflower growth. Enhancing cauliflower yield requires proper fertilization since it affects critical growth parameters like plant height, leaf count, and leaf area. The results of this study are in line with (Hong *et al.*, 2022), highlighting how crucial it is to apply fertilizer correctly in order to increase plant growth and productivity. For healthy growth and increased yields, plants must get the proper proportions of nitrogen (N), phosphorus (P), and potassium (K). Therefore, in hydroponic cultivations, it is vital to use a well-balanced fertilizer mixture like Albert's solution, which is essential for optimal plant growth. In this research, we tested three specific application rates of Albert's solution. Among them, 1.5g/plant/day and 2.0g/plant/day application rates resulted in noticeable improvements in growth parameters, including increased plant height and better leaf development. As noted by Samarakoon *et al.*, (2006), plants' rates of absorption of N, P, K, and Ca increased with increasing Albert's solution concentration. These findings highlight the importance of supplying plants with the right balance of nutrients, as provided by Albert's solution, to ensure efficient absorption and utilization, ultimately creating the ideal conditions for healthy and vigorous growth.

Further, nitrogen is essential for promoting healthy vegetative growth in plants. It plays a pivotal role in the formation of chlorophyll and proteins, both of which are vital for plant development. Without sufficient nitrogen, plants often experience stunted growth, pale foliage, and reduced yields (Dhakne *et al.*, 2023). A study by Muhammad *et al.*, (2024) on cauliflower showed that nitrogen fertilizer had a significant impact on plant height. When 275 kg of nitrogen per hectare was applied, the cauliflower plants grew to an average height of 72.5 cm, compared to just 46.1 cm in the control (no nitrogen). This clearly demonstrates the positive effect of nitrogen on the vegetative growth of cauliflower. Moreover, as stated by (Bhattacharya *et al.*, 2010), average height of the treated cauliflower plants was 52 cm, while the untreated plants only reached 40 cm. They found that the application of 100 kg of nitrogen per hectare considerably enhanced the height of the cauliflower plants. The researchers also observed that plant height continued to increase when nitrogen levels were raised to 200 kg per hectare. But beyond this point, the growth rate levelled off, suggesting that too much nitrogen delivery has no further effect on plant height. According to Devkota *et al.*, (2021), applying 210 kg N, 180 kg P, and 120 kg K per hectare produced a plant height of 75.33 cm and a curd spread of 26 cm, demonstrating the advantageous effects of balanced NPK fertilization on the growth characteristics of cauliflower. Results of the research clearly indicate that due to a significant interaction effect between the rate and split of fertilization although we increased the rate similar performances were obtained due to increment of splits in lower rates.

Also, the formation of leaves in cauliflower plants is greatly influenced by nitrogen application, which is essential for photosynthesis and general growth. Dharma *et al.*, (2023) stated that the application of 130 kg N/ha with three splits produced superior results in plant leaf area (264 cm^2) and number of leaves/plant (20.7). In contrast to lower leaf counts at lower nitrogen levels, Bhoya *et al.*, (2024) discovered that applying 175 kg N/ha produced an average of 21.98 leaves per plant at harvest. Similar to this, (KC *et al.*, 2022), showed that combining 50% nitrogen from urea with 50% from farmyard manure increased vegetative development by increasing the number of leaves per cauliflower plant. These results highlight the significance of sufficient nitrogen fertilizer in encouraging cauliflower leaf development, which improves photosynthetic capability and may raise production. Moreover, at the highest nitrogen levels, Muhammad et al. (2024) found that the leaf area was noticeably bigger than in the control group. Furthermore, they observed that the plants' increased intake of nitrogen produced ideal conditions for improved photosynthesis.

Also, the split fertilizer application is a crucial factor in optimizing growth, in addition to the nutrient composition. Split applications offer continuous nutrient availability, lowering the risks of nutrient loss through leaching and volatilization, according to studies on cauliflower and other crops. This method guarantees that plants get the nutrients they need at crucial growth stages, improving overall performance. In this study, significant increases in plant height, leaf count, and leaf area were observed with both thrice application of 1.5 g and 2.0 g Albert's solution. The potential for split applications to get comparable growth performance with 1.5 g/plant/day as opposed to 2.0 g/plant/day has important economic and environmental consequences. Lower fertilizer rates are more economical and sustainable for farmers since they lower input expenses. Split applications also reduce environmental nutrient loss, which lowers the possibility of water pollution and other ecological effects linked to excessive fertilizer use.

Welch *et al.*, (1987) observed that split applications enhance nitrogen uptake and use in cauliflower since a single dose of nitrogen applied at planting was less successful in open fields. After transplanting cauliflower in an open field, another study at the Institute of Agriculture and Animal Science in Nepal assessed six nitrogen rates (0, 70, 80, 90, 115, and 130 kg N/ha) with three distinct applications. Split nitrogen applications can improve cauliflower growth and productivity, as demonstrated by the improved plant height, leaf area, and yield obtained from the 130 kg N/ha application with three splits (Dharma *et al.*, 2023). Furthermore, studies on sweet potatoes have demonstrated that dividing nitrogen administrations improves growth and encourages the best yields at lower nitrogen rates. Although sweet potatoes were the subject of this study, the results indicate that split nitrogen applications might be advantageous for other crops, such as cauliflower (Du *et al.*, 2019). Additionally, most of these studies were limited to open fields rather than regulated hydroponic growth environments. Therefore, the rates and splits of fertilizer applications were different from those in controlled conditions under soilless cultures. Also, most of these research mainly focused on either the rate or split application of fertilizer. Therefore, as results indicated in this research, a significant interaction between the rate and split application of Albert's solution under protected house crop growing was a great milestone for farmers to increase their productivity while using low expenses for fertilizer. Because 1.5 g/plant/day with 3 splits and 2.0 g/plant/day with 3 splits showed similar growth performances of cauliflower.

Effect of rate and split application of Albert's solution on the yield of cauliflower

When considering the yield parameters, similar to growth parameters, there was a significant interaction ($p < 0.05$) between the rate and split application of Albert's solution on the yield characteristics of cauliflower cultivated in Sri Lanka's Low Country Wet Zone under protected house conditions.

Curd diameter

As Fig. 5 indicates, R2S3 (1.5 g/plant/day with 3 splits) obtained a significantly highest ($p < 0.05$) curd diameter (13.8 cm) when compared with other treatments at harvesting.

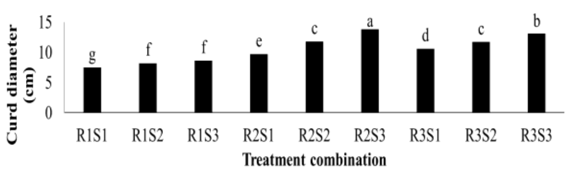

Figure 5. Effect of treatments on curd diameter at harvesting (8th week after transplanting). Means presented in bars with different letters are statistically different from each other at 5% probability level as determined by DMRT.

Total fresh plant weight

However, as in Figure 6, significantly higher ($p < 0.05$) fresh plant weight was gained from R2S3 (1.5 g/plant/day with 3 splits) and R3S3 (2.0 g/plant/day with 3 splits) when compared with other treatments at harvesting.

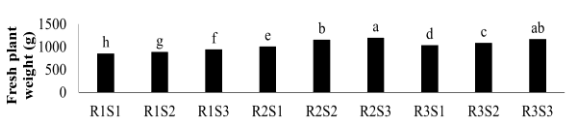

Figure 6. Effect of Treatments on fresh plant weight at harvesting (8th week after transplanting). Means presented in bars with different letters are statistically different from each other at 5% probability level as determined by DMRT.

Fresh curd weight

Same as curd diameter, significantly higher ($p < 0.05$) fresh curd weight (490.95 g) resulted from R2S3 (1.5 g/plant/day with 3 splits) compared to other treatments at the harvesting (Fig. 7).

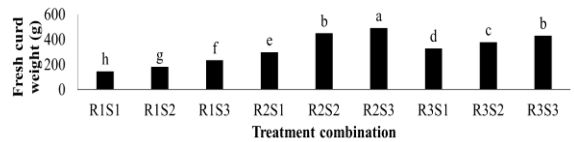

Figure 7. Effect of treatments on fresh curd weight at harvesting (8th week after transplanting). Means presented in bars with different letters are statistically different from each other at 5% probability level as determined by DMRT.

Harvest Index

As shown in Fig. 8, significantly the highest ($p < 0.05$) harvest index (40.9%) was detected in R2S3 (1.5 g/plant/day with 3 splits) compared to other treatments at the harvesting. Similar to other yield parameters, the significantly lowest ($p < 0.05$) harvest index (17.1%) was gained from R1S1 (1.0 g/plant/day with 1 split) compared to other treatment combinations.

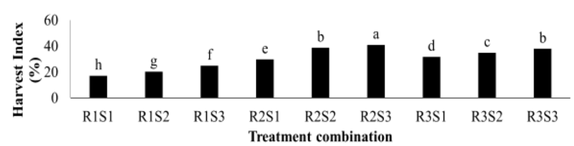

Figure 8. Effect of treatments on harvest index at harvesting (8th week after transplanting). Means presented in bars with different letters are statistically different from each other at 5% probability level as determined by DMRT

Nutrient uptake

During the research period, the mean temperature was recorded at 29°C, with a relative humidity of 84%, as reported by meteorological sources. These conditions are notably higher than the optimal temperature range for curd development, which is between 18°C and 20°C (Yadav *et al.*, 2023). Nevertheless, liquid fertilizers, such as Albert's solution, are known to enhance nutrient absorption because they provide nutrients in a readily available form. This advantage becomes particularly significant in environments with high temperatures and when using efficient soilless media like coconut coir, where split fertilization can be more effective, ensuring plants make the most of the available nutrients without waste. The study's results indicated that applying 1.5 g/plant/day and 2.0 g/plant/day of fertilizer produced similar outcomes as the number of splits increased, highlighting that these dosages are efficient in meeting the nutrient demands of plants under the tested conditions. By raising the dry matter content, plant height, and leaf count, liquid fertilizers can improve the metabolic processes of plants and encourage growth. Temperature accelerates metabolic responses until they reach an ideal level. Temperatures in the low country is greater than those in the upcountry, which naturally raises plant metabolic rates and nutrient uptake. Because plants are able to absorb the supplied fertilizer efficiently, there is less chance of nutrient waste (Kumarasinghe *et al.*, 2019). High temperatures and cauliflower's high nutritional requirements in the current study probably reduced any excess fertilizer. Therefore, 1.5 g/plant/day and 2.0 g/plant/day of fertilization perform the same manner with the increasing number of splits.

Nutrient Use Efficiency

To maximize yield and improve cauliflower growth, NPK treatment must be optimized. Research has shown that certain NPK application rates, when paired with certain splitting techniques, can have a major impact on plant development and increase curd weight. These findings suggest that splitting the NPK application enhances nutrient availability during critical growth stages, thereby improving metabolic activities and overall plant development. A key component of sustainable agriculture is nutrient use efficiency (NUE), which seeks to minimize environmental losses while increasing crop yield per unit of nutrients injected. It has been demonstrated that split fertilizer treatments increase NUE by matching crop demand at various growth stages with fertilizer availability. By lowering the chance of nutrient leaching and volatilization, this method guarantees that the plant uses a larger percentage of the applied nutrient (Govindasamy *et al.*, 2023). Depending on the kind of soil and the surrounding conditions, research has shown that the best N application rates for cauliflower production range from 150 to 240 kg/ha. For example, in open field research in Oregon, Hemphill and Jackson (1994) found that the yield of cauliflower increased with N application up to 270 kg/ha.

Additionally, the efficacy of nutrient administration is greatly influenced by the timing of its application. NUE and yield can be improved by split treatments, especially when they are timed to align with important developmental phases such as transplanting, curd initiation, and curd development. To enhance head yield and quality, for instance, the ideal combination of transplanting time and N:K ratio is crucial, according to a study on the impact of these factors on cauliflower yield and quality (Tallarita *et al.*, 2024). When nitrogen levels were increased, the researchers also noticed that plant yield kept rising. However, beyond a certain threshold, the yield metrics stabilized, indicating that excessive nitrogen delivery has no further impact on plant growth. The current research yielded the same results, 1.5 g/plant/day and 2.0 g/plant/day, with an increase in the number of fertilization splits while maintaining nutrient availability for plants grown hydroponically.

Conclusion

This study proves that 1.5 g/plant/day, along with 3 split applications of Albert's solution, and 2.0 g/plant/day, along with 3 split applications of Albert's solution, enhance the growth and yield performances of cauliflower grown under protected house conditions in the Low Country Wet Zone of Sri Lanka. Although the yield results from both fertigation techniques were similar, the 1.5 g/plant/day with three splits turned out to be the most cost-effective choice when taking fertilizer costs into account. It offers equivalent growth performance at a lower input cost.

These results provide important practical insights for growing cauliflower in Sri Lanka's Low Country Wet Zone. Farmers who prioritize sustainability and cost-effectiveness may confidently embrace the 1.5 g/plant/day with the three splits method without compromising productivity. By using this optimal fertigation technique, protected house farming methods may become more sustainable and effective by minimizing environmental impact, cutting production expenses, and reducing unnecessary fertilizer consumption.

Competing Interests

The authors have no competing interests to declare.

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