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GROWTH AND YIELD OF C*apsicum annuum* (BELL PEPPER) AS AFFECTED BY APPLICATION RATES AND SPLITS OF ALBERT'S FERTILIZER UNDER PROTECTED CULTIVATION IN THE LOW COUNTRY WET ZONE OF SRI LANKA

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ABSTRACT

A research study was performed to assess the impact of rates and split applications of Albert's fertilizer on the growth and yield of bell pepper under protected cultivation in the low-country wet zone of Sri Lanka. Bell pepper variety Polarized was cultivated in open-top grow bags filled with cocopeat as potting media. There were three levels of fertilization rates (R1-1.0 g/plant/day, R2-1.5 g/plant/day, and R3-2.0 g/plant/day) and 3 split applications (S1- 1 split/plant/day, S2-2 splits/plant/day, and S3-3 splits/plant/day). Two-factor factorial completely randomized design with nine treatment combinations and four replicates was used (2.0 g/plant/day fertilizer rate applied one split - R3S1 was the control). Treatments were administered daily. Plant height and the number of leaves/plants were assessed at two-week intervals, and leaf area was measured at monthly intervals as growth parameters. At harvest, fresh weight of fruits, fruit length, number of fruits per plant, and days to first flowering were assessed as yield parameters. The interaction effect of fertilization rate and split application had a significant impact on bell pepper growth and yield. The significantly higher plant height (157.1±3.2 cm), number of leaves per plant (115.1±1.7/plant), leaf area (86.8±1.4 cm^2), number of fruits (11.3±0.5/plant), fruit length (8.3±0.2 cm) and fresh total fruit weight/plant (2.14±3.51 kg) were recorded from 1.5 g/plant/day as three split applications of Albert's fertilizer compared to other treatment combinations. Accordingly, the study demonstrated that in the low-country wet zone of Sri Lanka, bell pepper growth and yield are improved by 1.5 g/plant/day as three split applications of Albert's fertilizer under protected cultivations.

Keywords: Albert's fertilizer, Bell pepper, Growth and yield, Hydroponics, Protected cultivation, Rates and split applications of fertilizer

INTRODUCTION

Global food security is threatened by rapid population growth, which strains natural resources and different agricultural farming methods. This need usually exceeds the ability of agricultural systems to sustainably produce enough food to fulfil the demands of a growing population. The problem is intensified by climate change, which modifies weather patterns and results in extreme weather events that reduce crop productivity (Hall et al., 2017). Thus, the majority of agricultural nations are moving toward protected agriculture with the intention of dealing with the challenging situations brought by population expansion and food insecurity.

According to Kumara et al. (2015), protected agriculture is the practice of growing crops in enclosed spaces such as net houses and polytunnels that have controlled microenvironmental settings to provide the best conditions for plant growth and development. Effective utilization of agricultural inputs, increased yields, and resilience to environmental stresses are some benefits of this strategy. Additionally, protected agriculture helps smallholder farmers to improve their living status and diversify their revenue by producing high-value vegetables that command high prices in both domestic and international markets, such as bell pepper, tomato, and salad cucumber (Kumara et al., 2015). Furthermore, aggregate hydroponic systems are the most often used type of hydroponic system worldwide for protected farming. In aggregate hydroponic systems in Sri Lanka, coconut coir peat is the most commonly used growth substrate. Because coconut coir peat is one of the best-growing media for hydroponics based on its favorable qualities, which include high porosity, a slight acidity, a high cation exchange capacity, and an optimal water holding capacity (Mawalagedara et al., 2012). Even in this type of regulated environment, however, the main problem faced by Sri Lankan farmers is providing an accurate amount of nutrients for crops.

Therefore, sustainable farming depends on efficient nutrient management, especially for crops with high demand like bell pepper. According to Coolong et al (2019), the overuse of water and fertilizer in agriculture has become popular as a way to boost production. However, this often leads to nutrients and water being wasted, reducing the efficiency of both nutrients and water. Thus, improper fertilizer use for vegetable production has drawn increasing scientific attention (Karunarathne et al, 2022). However, high-value crops such as bell pepper still lack crop-specific fertigation patterns under regulated settings. Understanding how crops react to different amounts of fertilizer and water is essential to resolving these issues. This understanding is essential for enhancing agricultural practices, maximizing nutrient utilization, and reducing the adverse environmental effects of excessive fertilizer application. For example, splitting fertilizer treatments can be a useful tactic to improve plant nutrient uptake.

Additionally, inorganic fertilizers are the primary source of plant nutrition in a controlled environment. Weerakkody et al. (2002) stated that use of Albert's fertilizer is regarded as the major hydroponics fertilizer mixture that is balanced. Drip irrigation systems, which are common in protected agriculture, can be successfully integrated with it to ensure superior nutrient uptake while minimizing losses. However, protected agriculture in Sri Lanka's low-country wet zone has not yet examined the growth and yield performances of bell peppers with rate and split application of Albert's fertilizer.

This study aims to address this gap by identifying the optimal fertilizer application strategy for maximizing the growth and yield of bell pepper in protected cultivation systems in this region. The findings are expected to contribute positively to both environmental sustainability and the socio-economic well-being of farming communities.

METHODOLOGY

The experiment was conducted in a 92.9 m^2 polytunnel in the Low Country Wet Zone (WL2) at the Faculty of Agriculture, University of Ruhuna, Sri Lanka. During the period of October 2021 to January 2022, the experiment was carried out. According to meteorological reports, the average temperature and relative humidity in the Mapalana area during the study period were 29±2 °C and 84±4%, respectively. Bell pepper variety 'Polarized' (F1 hybrid) was used in the experiment. The experiment was conducted using 23 x 20 x 23 cm^3 open-top grow bags filled with cocopeat. The growing bags were spaced 60 cm apart from one another. Albert's fertilizer (N = 10.6%, P = 9.3%, K = 16.3%, Ca = 11%, Mg = 2.25%), one of the commercially available inorganic fertilizers, was used in the experiment. The bell pepper crop management guidelines from the Department of Agriculture, Sri Lanka, were adhered in accordance with the crop's developmental stages (DOA, n.d.). In a coir pellet nursery, seedlings were produced. After 28 days of the nursery period, uniform and vigorous seedlings were selected to transplant in open-top grow bags.

After five days following transplantation, treatments were started to apply. The primary factors that were evaluated were fertilization rate (R) and split of application (S). There were three fertilization rates (1.0 g/plant/day, 1.5 g/plant/day and 2.0 g/plant/day) and three split applications of fertilizer (1 split/plant/day, 2 splits/plant/day and 3 splits/plant/day). In here, 1 split, 2 splits and 3 splits were one time, two times and three times, respectively, per day. Thus, there were nine treatment combinations (Table 1). A two-factor factorial completely randomized design with four replicates (one replicate contained three plants) was used for the experiment. 2.0 g/plant/day fertilizer rate applied as 1 split (R3S1), which is the control was the framers' current practice (Karunarathne et al., 2021).

Seven to eight in the morning, ten to eleven in the morning, and one to two in the afternoon were the times for the first, second, and third split applications, respectively. Ultimately, each plant was given 200 ml of Albert's fertilizer with their specific fertilizer amount at the end of the day. Daily treatments were administered manually to the plants. All the treatments were recorded at an acceptable EC level of 1.5 – 2.5 dS/m and pH 5.8 - 6.5.

Table 1: Treatment combinations of the experiment

Main factors		
Rate of fertilization (R)	Split of fertilization (S)	Treatment combinations
R1 (1.0 g/plant/day)	S1 (1 split /day)	R1S1 – (T1)
	S2 (2 splits /day)	R1S2 – (T2)
	S3 (3 splits /day)	R1S3 – (T3)
R2 (1.5 g/plant/day)	S1 (1 split /day)	R2S1 – (T4)
	S2 (2 splits /day)	R2S2 – (T5)
	S3 (3 splits /day)	R2S3 – (T6)
R3 (2.0 g/plant/day)	S1 (1 split /day)	R3S1 – (T7)
	S2 (2 splits /day)	R3S2 – (T8)
	S3 (3 splits /day)	R3S3 – (T9)

A common irrigation schedule was followed for all the treatment combinations. Three splits of 800 ml of water were given to each plant at the end of the day. From the first and second splits, 300 ml of water was given to each plant independently while 200 ml of water was given to each plant during the final split. Additionally, a common schedule for applying fungicides, insecticides, and other chemicals was used as a prevention technique for diseases and pests.

In order to measure growth parameters, plant height (from base of the plant to the insertion of the apical meristem), number of leaves per plant (by counting totally expanded leaves with a minimum length of 3 cm) at biweekly, and leaf area at monthly intervals were measured for 12 weeks. Each plant was divided into three layers as upper, middle and lower. From each layer randomly selected three leaves were randomly selected to measure leaf length and width. From each selected leaf length and width were recorded for three different places. Finally average values were taken to calculate leaf area using equation 1.

LA = 0.60 x W x L ……………………..Equation 1

Where, LA = leaf area (cm^2), 0.60 = Correction factor, W = Leaf width (cm), L = Leaf length (cm).

Number of fruits per plant, fresh total fruit weight and length of fruit at harvest, as well as the time taken for initial flowering, were considered as yield parameters during 12 weeks after transplanting.

The experimental design was 3 x 3 two factor factorial completely randomized design with four replicates. Data were statistically analyzed using Analysis of Variance (ANOVA) from the Statistical Analysis System (SAS) 9.1.3 version. Then, treatment mean differences were compared at the 5% probability level using Duncan's New Multiple Range Test.

RESULTS AND DISCUSSION

Effect of rate and split applications of Albert's fertilizer on growth of bell pepper

The findings demonstrated a significant interaction ($p<0.05$) between the rates and splits of Albert's fertilizer application on the growth parameters of bell peppers grown under protected house settings in Sri Lanka's low-country wet zone. The mean plant height was significantly higher ($p<0.05$) with 1.5 g/plant/day as 3 splits (R2S3) and 2.0 g/plant/day as 3 splits (R3S3) from the 2nd week to the 8th week after transplanting, as shown in Table 2 and Figure 1. However, after 10 weeks of transplanting, when compared to other treatment combinations, R2S3 showed the significantly highest ($p<0.05$) result in terms of mean plant height. As shown in Table 3 and Figure 2, R2S3 obtained significantly the highest ($p<0.05$) mean number of leaves per plant when compared with other treatment combinations at 4th, 6th and 12th weeks after transplanting onwards. Despite this fact, the mean number of leaves per plant in both R2S3 and R3S3 treatment combinations was significantly higher ($p<0.05$) than in other treatment combinations in the 8th and 10th weeks following transplanting. Furthermore, as compared to other treatment combinations, 1.0 g/plant/day with 1 split (R1S1) produced significantly the lowest ($p<0.05$) performances throughout the experimental period from the 2nd week to the 12th week. In comparison to other treatment combinations, Table 4 and Figure 3 showed that during 4 to 12 weeks period after transplanting, the R2S3 and R3S3 treatment combinations recorded a significantly higher mean leaf area. Similar to the number of leaves per plant, the R1S1 treatment combination produced the significantly lowest leaf area. Thus, according to the above results, the growth of bell peppers is greatly influenced by the rates and splits of fertilizer application.

Improving bell pepper yield necessitates appropriate fertilization as it influences key growth factors such as plant height, leaf number, and leaf area. The findings of this research emphasized the importance of properly applying fertilizer to enhance plant growth and productivity. In this study, we examined three particular application rates of Albert's fertilizer.

Table 2: Effect of treatment combinations on mean plant height at different weeks after transplanting

Treatment combination	Mean plant height at different weeks after transplanting (cm)					
	2nd week	4th week	6th week	8th week	10th week	12th week
R1S1	17±0.4^{f}	27.4±1.1^{h}	51.8±1.4^{g}	82.4±1.4^{f}	108.1±0.5^{h}	118.5±1.9^{g}
R1S2	20.2±0.6^{e}	30.3±0.9^{g}	55.1±1.2^{f}	86.5±1.6^{e}	113.1±0.5^{g}	126.9±0.6^{f}
R1S3	22.2±1.0^{d}	34.2±0.3^{f}	58.4±0.9^{e}	89.9±1.0^{d}	117.3±0.4^{f}	130.7±0.6^{e}
R2S1	23.5±0.7^{c}	36.7±0.8^{e}	64±1.8^{d}	95.5±1.0^{c}	123.8±0.4^{e}	136.7±1.0^{d}
R2S2	28.2±0.7^{b}	45.1±1.5^{c}	72.3±0.4^{b}	104.5±2.2^{b}	131.6±1.0^{b}	145.1±2.2^{c}
R2S3	30.9±0.8^{a}	51.4±0.7^{a}	80.8±0.7^{a}	115.6±2.5^{a}	138.2±0.1^{a}	157.1±3.2^{a}
R3S1	27±0.5^{b}	40.6±0.4^{d}	65.9±0.9^{c}	96.7±0.9^{c}	126.6±0.7^{d}	138.8±1.3^{d}
R3S2	27±0.5^{b}	47.1±1.5^{b}	72.6±1.2^{b}	104.1±5.1^{b}	128.3±1.3^{c}	143.1±1.4^{c}
R3S3	30.5±0.9^{a}	50.7±1.5^{b}	80.4±1.2^{a}	113.1±0.8^{a}	131.7±2.0^{b}	152±3.1^{b}

Means are presented in columns with different letters are statistically different from each other at 5% probability level as determined by DMRT

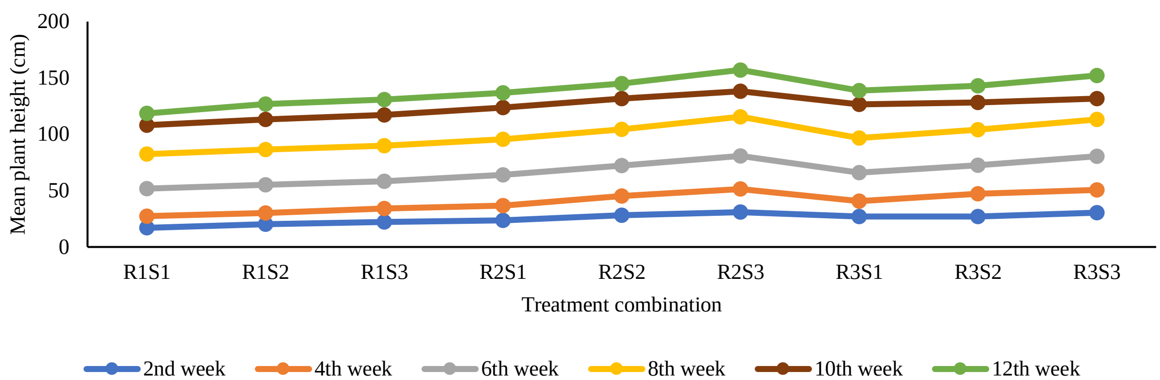

Figure 1: Effect of treatment combinations on mean plant height at different weeks after transplanting

Table 3: Effect of treatment combinations on mean number of leaves per plant at different weeks after transplanting

Treatment combination	Number of leaves per plant at different weeks after transplanting					
	2nd week	4th week	6th week	8th week	10th week	12th week
R1S1	5.6±0.5^{f}	25.5±0.4^{g}	40.1±0.5^{g}	40.1±0.6^{h}	65.3±0.6^{f}	62.3±0.6^{h}
R1S2	6.8±0.3^{e}	30.0±0.4^{f}	43.5±0.4^{fg}	43.5±0.6^{g}	64.9±0.8^{e}	69.4±0.9^{g}
R1S3	7.6±0.3^{d}	36.0±0.7^{e}	46.5±0.4^{f}	46.5±0.2^{f}	69.0±0.7^{e}	75.8±0.6^{f}
R2S1	8.8±0.3^{ab}	39.8±0.3^{d}	55.5±0.4^{e}	55.5±0.4^{e}	74.6±0.9^{d}	82.5±1.7^{e}
R2S2	7.6±0.6^{d}	47.3±0.6^{bc}	69.0±0.9^{c}	69.0±1.3^{c}	87.8±0.8^{b}	96.0±1.1^{c}
R2S3	8.5±0.4^{be}	51.8±0.3^{a}	85.5±1.1^{a}	85.5±1.0^{a}	104.7±0.5^{a}	115.1±1.7^{a}
R3S1	7.4±0.5^{de}	41.3±0.6^{d}	60.4±1.0^{d}	60.4±0.8^{d}	79.9±0.6^{c}	90.0±0.9^{d}
R3S2	8.0±0.4^{cd}	45.4±1.1^{c}	68.3±0.9^{c}	68.3±1.7^{b}	90±2.6^{b}	97.1±1.9^{c}
R3S3	9.1±0.3^{a}	48.8±0.9^{b}	78.8±1.0^{b}	78.8±0.9^{a}	99.8±1.0^{a}	108.8±0.6^{b}

Means are presented in columns with different letters are statistically different from each other at 5% probability level as determined by DMRT

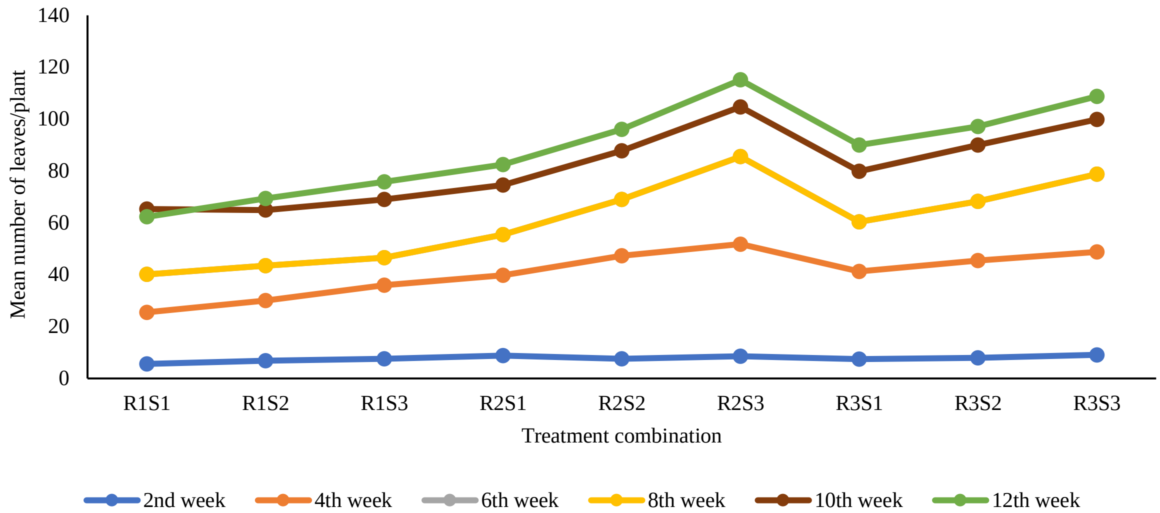

Figure 2: Effect of treatments on mean number of leaves per plant at different weeks after transplanting

Table 4: Effect of treatment combinations on mean leaf area at different weeks after transplanting

Treatment combination	Mean leaf area at different weeks after transplanting (cm^2)		
	4th week	8th week	12th week
R1S1	7.5±0.3^g	37.4±1.6^f	69.9±1.2^g
R1S2	9.1±0.9^f	43.1±0.3^e	74.0±1.3^f
R1S3	10.2±0.7^e	44.2±0.5^e	76.4±0.4^e
R2S1	12.3±0.4^d	46.4±0.6^d	78.0±1.1^d
R2S2	16.3±0.6^b	49.9±1.3^c	81.2±0.6^c
R2S3	18.8±0.4^a	56.5±0.9^a	86.8±1.4^a
R3S1	14.8±0.6^c	48.0±1.2^d	80.3±0.9^c
R3S2	15.9±0.6^b	50.7±2.6^c	83.5±1.8^b
R3S3	18.4±0.6^a	54.2±1.4^b	87.8±1.9^a

Means are presented in columns with different letters are statistically different from each other at 5% probability level as determined by DMRT

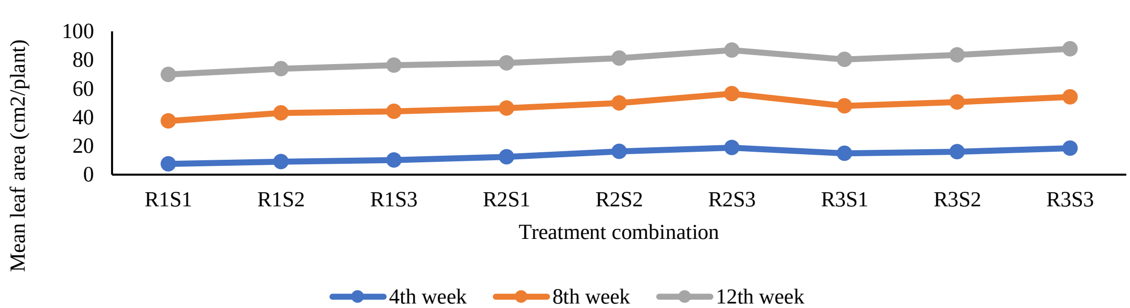

Figure 3: Effect of treatments on mean leaf area per plant at different weeks after transplanting

Of these, 1.5 g/plant/day and 2.0 g/plant/day application levels led to significant enhancements in growth metrics. According to Shah et al. (2016), for optimal growth and higher yields, plants require the right balance of nitrogen (N), phosphorus (P), and potassium (K). Hence, in hydroponic farming, it is crucial to utilize a well-balanced fertilizer blend such as Albert’s solution, which is important for ideal plant development. Further, plants absorbed N, P, K, and Ca at higher rates as the concentration of Albert's fertilizer increased, according to Samarakoon et al. (2006). These results demonstrate how vital it is to provide plants with the proper ratio of nutrients, as supplied by Albert's fertilizer, in order to guarantee effective absorption and utilization and, eventually, to create the best circumstances for robust and healthy plant development.

According to Prem et al. (2024), applying 0%, 50%, 100%, and 150% of the recommended NPK doses resulted in the maximum plant height of 47 cm and the greatest number of leaves (165) from 50%, indicating the beneficial effects of balanced NPK fertilization on bell pepper growth characteristics. The present findings showed that bell pepper performance was not enhanced by excessive doses. Moreover, this frequently results in nutrients being carried to deeper soil layers from the topsoil, decreasing the effectiveness of both water and nutrients. Moreover, nitrogen is necessary to support plants' healthy vegetative development. It is essential for the synthesis of proteins and chlorophyll, two substances that are critical for plant growth. Plants frequently suffer from stunted development, pale leaves, poor flowering and decreased yields when nitrogen levels are insufficient (Prem et al., 2024). According to Sajjad et al. (2025), this splits application of fertilizer encourages healthy plant development with high nutrient availability to plants while lessening the negative impacts caused by over-chemical fertilizer usage on the environment. Therefore, according to current research results, split applications provide continuous nutrient availability, reducing the chances of nutrient loss through leaching and volatilization. By using this technique, plants are guaranteed to receive the nutrients that they require throughout critical growth phases, which enhances overall performance. This study found that applying 1.5g and 2.0g of Albert's fertilizer as three splits resulted in substantial increases in plant height, leaf count, and leaf area. The possibility that split applications might achieve similar growth performance with 1.5 g/plant/day as opposed to 2.0 g/plant/day has significant environmental and economic ramifications. Additionally, lower fertilizer prices reduce input costs, making them more sustainable and cost-effective for farmers. In open fields, a single nitrogen dose at the vegetative stage was less effective, thus Russo (1991) found that three split applications improve nitrogen absorption and utilization in bell pepper. Furthermore, rather than controlled hydroponic growing conditions, most of these researches were restricted to open fields. Fertilizer application rates and splits were therefore different from those under hydroponic cultures. Furthermore, the majority of these studies primarily examined fertilizer application rates or splits. Thus, as the study's findings showed, a crucial relationship between Albert's fertilizer's rate and split application during protected house crop growth was an immense step forward for farmers looking to boost output while spending less on fertilizer.

Effect of rates and splits application of Albert’s fertilizer on yield of bell pepper

There was a significant interaction ($p<0.05$) between the rates and splits application of Albert's fertilizer on the yield parameters of bell pepper except for days taken to first flowering. However, the time taken for flowering was not even individually significant ($p>0.05$) with rates and splits application of Albert’s fertilizer. It was recorded 29 days after transplanting to the first flower set. As shown in Figure 04, R2S3 (11.3±0.5) and R3S3 (11.1±0.7) produced a significantly higher mean number of fruits/plants at harvesting than other treatment combinations. Additionally, during harvest, R2S2 (7.7±0.1 cm), R2S3 (8.3±0.2 cm), and R3S3 (7.8±0.2 cm) treatment combinations produced significantly longer fruits than other treatment combinations (Figure 5). Same as fruit count, significantly higher total fresh fruit weight per plant was recorded from R2S3 (2.14±3.51 kg) and R3S3 (2.03±6.58 kg) treatment combinations compared to other treatment combinations (Figure 6).

According to the results, rates and splits application of fertilizer had to be adjusted to increase yield and

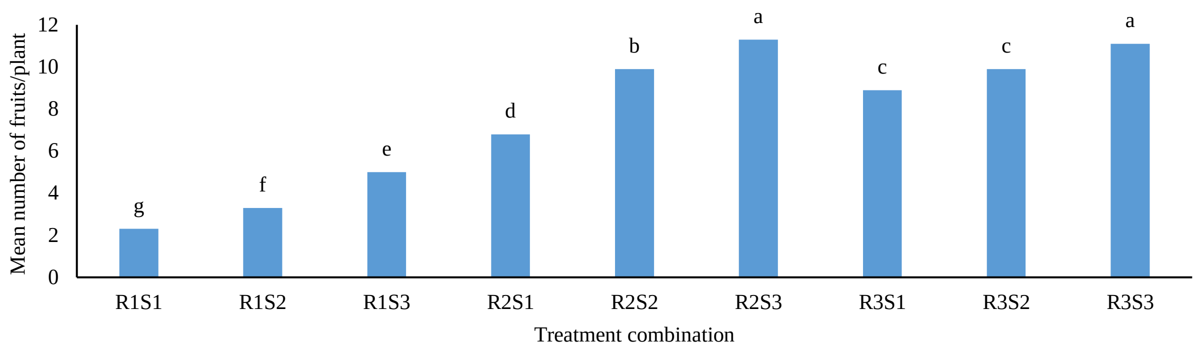

Figure 4: Effect of treatments on mean number of fruits/plants at harvesting (up to 12th week after transplanting) Means presented in bars with different letters are statistically different from each other at 5% probability level as determined by DMRT

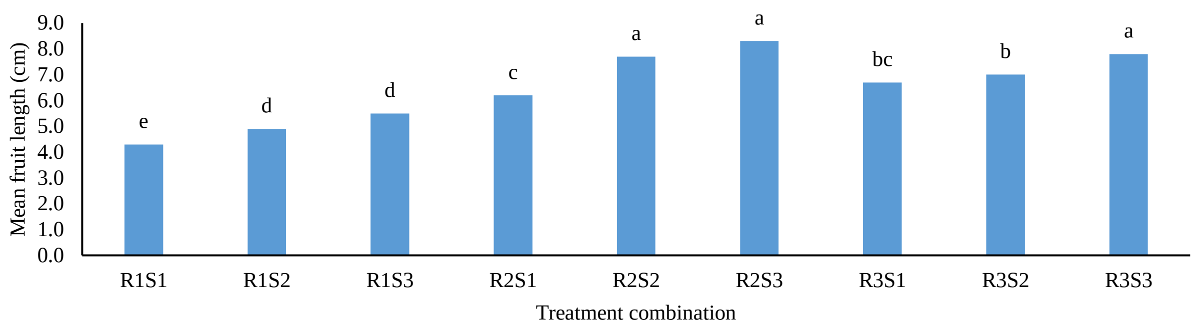

Figure 5: Effect of treatments on mean fruit length at harvesting (up to 12th week after transplanting) Means presented in bars with different letters are statistically different from each other at 5% probability level as determined by DMRT

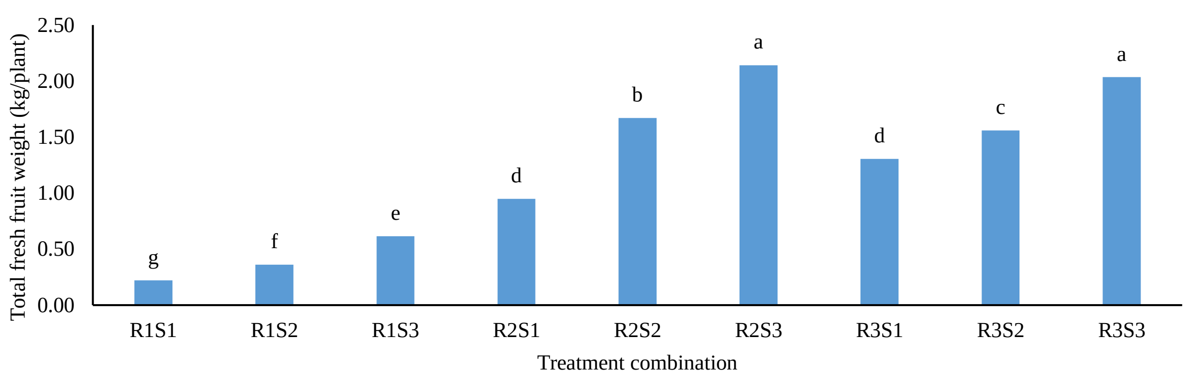

Figure 6: Effect of treatments on Total fruit weight per plant at harvesting (up to 12th week after transplanting Means presented in bars with different letters are statistically different from each other at 5% probability level as determined by DMRT

enhance bell pepper growth. Therefore, this study has indicated that specific fertilizer rates combined with specific splitting methods can significantly influence plant growth and boost fruit weight. According to these results, dividing up the fertilizer application improves nutrient availability during the reproductive phase, which in turn boosts metabolic processes and the general reproductive development of plants. Nutrient Use Efficiency (NUE), which aims to maximize crop output per unit of nutrient injected while minimizing environmental losses, is a crucial element of sustainable agriculture (De Silva et al., 2020). Split nutrient applications have been shown to improve NUE by balancing fertilizer supply with crop demand at different growth phases. Additionally, De Silva et al. (2020) recorded that a fertilizer rate of 5.51 g/plant compared to other treatments ranging from 0 to 6.5 g/plant gave the highest fruit yield. Also, from this study, they found that the NUE decreased and the residual mineral content in the substrate rose as the nutrient rate increased appropriately.

The time of the application of fertilizer and method of application also have a significant impact on crop yield. When split treatments are timed to coincide with critical developmental stages like fruit setting, blooming, and transplanting, they can increase nutrient use efficiency and yield. For example, a study on the effects of these parameters on bell pepper production and quality found that the optimal combination of transplanting time, first flower set and fruit development, and split application essential to improve output and quality of bell pepper in open field conditions (Russo et al., 1991). As nutrient levels rose, it was also observed that plant production continued to increase. However, after a while, the yield parameters leveled out, suggesting that too much nutrient administration had no more effect on plant development. Same as this, the current study also found that plants cultivated hydroponically required more number of fertilizer splits while preserving nutrient availability, yielding the same outcomes of 1.5 and 2.0 g/plant/day.

According to Mufeetha et al. (2021), the ideal temperature range for fruit development of bell pepper is between 21°C to 25°C, which is somewhat lower than temperature prevailed during experimental period (29°C). Albert's solution and other liquid fertilizers, however, are proven to improve nutrient absorption since they supply nutrients in an easily accessible form. Split fertilization, which ensures plants use all of the available nutrients without wasting any, can be more successful in high-temperature conditions and when utilizing an efficient soilless medium like coconut coir (Kumarasinghe et al., 2016). According to the study's findings, fertilizer applications of 1.5 and 2.0 grams per plant per day provided comparable results as the number of splits rose, demonstrating that both doses are effective in satisfying the nutritional requirements of plants in the investigated conditions. Additionally, liquid fertilizers can enhance plant metabolism and promote growth by increasing dry matter content. The temperature speeds up metabolic reactions until they are at their optimal level. Plant metabolic rates and nutrient absorption are naturally increased by the higher temperatures in the low country compared to the upcountry. Kumarasinghe et al. (2016) reported that nutrient waste is less likely since plants can effectively absorb the fertilizer with higher temperature. Therefore, the current study is also in line with these findings. The present study discovered that hydroponically grown plants enhance their growth and yield by applying a greater number of fertilizer splits while maintaining optimum nutrient availability, producing the same results of 1.5 and 2.0 g/plant/day.

CONCLUSION

This study demonstrates that the growth and yield performances of bell peppers grown in protected house conditions in Sri Lanka's low country wet zone are improved by 1.5 g/plant/day along with three split applications of Albert's fertilizer, which is cost-effective when considering the price per unit weight of fertilizer.

Conflict of interest

There are no conflicts of interest and no financial or other support that could have influenced the results or interpretation of this research.

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