ISSN 1391-0256

Journal of the Sri Lanka Association for the Advancement of Science

Volume 6 Issue 2, 2024

JSLAAS

Founded in 1944 and incorporated by the Act of Parliament No 11 of 1966.

Journal of the Sri Lanka Association for the Advancement of Science is a biannual publication. Selected research work from annual research sessions (based on scientific merit) as well as other research articles are invited to submit research manuscripts as per the guidelines provided by SLAAS. SLAAS members may also separately submit their papers for publication. The Journal can be accessed on-line to view and download the full text of the articles published respective to the volumes free of charge

Submission Manuscript

Only online submission, Web: https://journal.slaas.lk, e-ISSN: 2682-6992

Exchanges: Please address all requests to the Secretary, *Sri Lanka Association for the Advancement of Science, "Vidya Mandiraya" 120/10, Wijerama Mawatha Colombo 07, Sri Lanka*

Table of Contents

		Page
1	Identification of the Adaptation Strategies to Mitigate Flash Flood Risk in Sri Lanka – Case Study in Ja-Ela *W A U D Perera, N K N M Nakkawita, H P A M Siriwardana, R S M Samarasekara*	4
2	Growth and Yield Performances of Cabbage Grown under a Protected House in Low Country Wet Zone of Sri Lanka as Affected by Artificial Lights and Rate of Albert Fertilizer U D T Perera , S Subasinghe, K K L B Adikaram, H K M S Kumarasinghe, M K D K Piyaratne	17

Identification of the Adaptation Strategies to Mitigate Flash Flood Risk in Sri Lanka – Case Study in Ja-Ela

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ABSTRACT

Flash floods pose a global threat due to their destructive nature, particularly in densely populated urban areas, causing substantial economic loss. As a developing country, urban areas in Sri Lanka also face this issue frequently. The study investigates the consequences of sudden flash floods in a vulnerable region as the case study area within the Waligampitiya Grama Niladari Division (GND) in the Ja-Ela District. This study aims to identify the adaptation strategies to mitigate the impact of flash floods in Sri Lanka. The methodology involves conducting interviews with government officers in the Ja-Ela division and the District Disaster Management Centre, extracting data from situation reports, reviewing data, site observations, photographic survey, analyzing rainfall data from the Department of Meteorology Sri Lanka and land use data from Survey Department and Municipal Council. Interviews identified flash flood risk and management techniques, providing a comprehensive analysis for effective strategies and plans to address the identified issue. Then the final objective of the study entails proposing suggestions, which will be achieved by reviewing strategic plans, the relevant literature on best practices, and the analysis of adopted strategies from developed and developing countries. The strategies to be employed in Ja-Ela to mitigate flash flood damage involved real-time flood mapping and notification systems, awareness and preparedness activities, and stakeholder engagement. This study presents effective flash flood mitigation options for implementation in Ja-Ela, which can serve as significant insights for any other flood mitigation project of a similar nature.

KEYWORDS: Adaptation Strategies, Flash Flood, Flood Risk Mitigation, Sri Lanka, Suggestions

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INTRODUCTION

Background

Flash flood is one of the major natural phenomena with significant social and economic impacts. They are sudden surges in water levels due to intense precipitation or the sudden discharge of impounded water, posing a threat to human safety and requiring a brief storm duration (Hong et al., 2013). According to Mohamad & Rosmiza, (2023) Flash floods have a major effect on the populace and, especially in industrialized areas, seriously harm infrastructure and human health. They also cause substantial damage to property, transportation, buildings, and crops. Moreover, these events can cause traffic congestion, disrupt services, and cause damage to vital infrastructure like buildings, bridges, and drainage systems (Chaturani & Jayarathne, 2019).

Urban flash floods have increased in recent decades, primarily due to heightened rainfall intensity, inadequate drainage infrastructure, alteration patterns, and wetland reclamation (Abd-Elaty et al., 2023). Climate change models indicate an increased probability of frequent extreme rainfall events, which in turn raises the potential for flash floods (Hamdy et al., 2023). In addition, these flood events can be amplified by fluctuations in the occurrence of extreme weather and climate events, ultimately resulting in significant economic and socio-environmental consequences (Forero-Ortiz et al., 2020).

Abdelkareem & Mansour, (2023), emphasizes that the rapid development of intense surface runoff is facilitated by factors such as the existence of a shallow soil layer, steep slopes, and the placement of impermeable structures like buildings and roads. Hence, identifying vulnerable areas to flash floods is more challenging than riverine floods. Unplanned areas with a lack of permanent drainage systems and excluded from standard meteorological and hydrological measures, making them prone to sudden and intense runoff, leading to flash floods.

Global Facilities for Disaster Reduction and Recovery (GFDRR) annual report identified the small developing islands are having a common similarity as they can be identified as the countries that have a high susceptibility to exposure to natural hazards and climatic change (GFDRR, 2016). Therefore, Sri Lanka as a small developing island can fall under that category. As a result of Sri Lanka being situated near Bengal Bay, the pressure difference in the bay and the heavy wind can cause unforeseen heavy rains. The research was done by Samarasinghea et al. (2010), obtained that the Kalu Ganga, Kelani Ganga, and Gin Ganga are the areas that are most frequently exposed to floods due to the two monsoons. Hence in this Research Ja Ela district was selected to conduct the case study which is situated in the Ja Ela Basin.

Community Resilience and Preventive Steps Towards the Effects of Flash Floods

Flash floods provide substantial hazards to communities, especially in residential and economic zones, necessitating preventive actions to save lives and economic activities. These include effective land use planning, resilient infrastructure, early warning systems, community engagement in disaster preparedness, and building the capacity of local institutions to manage flood risks (Siriwardana et al., 2018). Prioritizing human settlement safety and resilience can mitigate flash flood impacts, promote community well-being, and foster sustainable development.

Starzec et al., (2023), highlights the importance of establishing a proper early warning system and implementing an efficient disaster management plan. Forecasting and monitoring flash floods in specific spatial and chronological contexts require analyzing precipitation input and catchment risk. Using the Geographic Information System (GIS) is the most predominant technique for identifying catchments at risk for flash floods. According to Lyu et al. (2019), individual cities or whole countries can be considered at once for such studies. Accurate maps with precise elevation data are essential for evaluating and modelling spatial data to identify flood-prone areas. Forero-Ortiz et al. (2020), also indicates the need to pay special attention to metropolitan areas, particularly those with major underground structures like metro systems, as flooding events pose a significant threat to underground transportation.

Spatial planning is widely recognized as a crucial tool for effectively managing the consequences of climate change and promoting adaptation in spatial settings, especially in terms of limiting the negative impacts of sudden floods. This is especially important considering the continuous changes in land cover and the expansion of urban settlement systems (Bakker, 2022). Flash flood risk management requires intersectoral coordination and is supervised by many institutions and state administrative organizations at various levels of territorial subdivision within nations. Achieving comprehensive collaboration among governmental bodies proficient in risk management, encompassing population safeguarding, spatial arrangement, and sector-specific endeavours such as water management, remains an ongoing obstacle in Sri Lanka compared to the global context (Abdeen et al., 2021).

Flash floods pose a global concern, and Sri Lanka must enhance its flood mitigation techniques by examining the implementations undertaken by other nations which can develop in two forms which are structural and non-structural measures. For example, Bodoque et al. (2019), presents the implementation of several flood mitigation measures in Spain aimed at mitigating flood threats. These strategies primarily include structural interventions such as levees and flood storage reservoirs, as well as non-structural interventions like land use planning. In addition, Li et al. (2020) explore a concept for reducing flash floods in urban areas known as sponge city technology. This approach involves designing urban areas to function like a sponge, storing rainwater and releasing it during periods of water scarcity. He analysed the efficacy of this approach, drawing on the case study of Central Geelong. In addition, being a developing nation, Pakistan is using several household technologies to mitigate the risks associated with flooding. The recognized key mitigation techniques applied to secure lives and property from flood hazards are elevated ground floor, emergency savings, house building with strengthened materials, and stabilised foundation (Ahmad & Afzal, 2020). Therefore, this study aims to identify the tactics implemented by government officials and bodies, municipalities, residents, and the public in Sri Lanka to mitigate the risks of flash floods. The study compares metrics from developed and developing countries, emphasizing the necessity of knowing the community's approach to preparedness, evacuation, and reaction to such dangers. To achieve this goal, a particular area in Ja-Ela, Sri Lanka, which regularly encounters these flash floods, was selected as a case study area to understand the importance of effective adaptation techniques in reducing the effects of possible flash flood hazards.

This research intends to evaluate the effectiveness of the current mitigation measures in the Ja-Ela division and propose ways to enhance preparedness and resilience to hazards in the region. Therefore, the research has identified three objectives which are as follows: The first objective is to identify the flash flood risk in Sri Lanka. The second is to ascertain the measures used by the central government, municipal governments, communities, and individuals to mitigate the impacts of flash floods in Sri Lanka. The third objective is to propose suggestions for reducing the consequences of flash floods in Sri Lanka by examining and comparing the strategies adopted in both developed and developing countries.

METHODOLOGY

Case Study Area

To initiate the process, a comprehensive desk study was conducted to collect pertinent information regarding the area. Hence, we gathered the geographical, authorised departments, and relevant background information of the study area. The Weligampitiya North GND area in Ja-Ela where the Ekala-Gampaha Road and A33 road meet is a rapidly developing region. The Ja-Ela Urban Council area and the Ja-Ela Pradeshiya Sabha are the twoadministrative divisions that make up Ja-Ela town. This area is vulnerable to flash flooding due to its flat terrain, located in a coastal lowland, and human-induced factors. Moreover, the Ja Ela basin is characterized by physically flat topography, with an average fluctuation in elevation of 9 meters above mean sea level (MSL). In addition, during the process of gathering background information on the study region, it was noted that the Muthurajawela Marsh and Negombo Lagoon are natural wetlands located near the Weligampitiya GND. Wetlands provide a huge service to the ecosystem in terms of flood prevention, wastewater treatment, and shallow coastal fisheries Kotagama & Bambaradeniya, (2006). However, according to the research done by Athukorala et al. (2021), obtained that there was a massive development of the population density in this area which caused the loss of the wetlands. Under this research, it was obtained that the land use/land cover expanded near the road and the growth nodes including Ja Ela. Furthermore, he states that the construction of the new Katunayake expressway is one of the major reasons for this population development as Ja Ela is situated at the intersection node of the Katunayake – Colombo expressway.

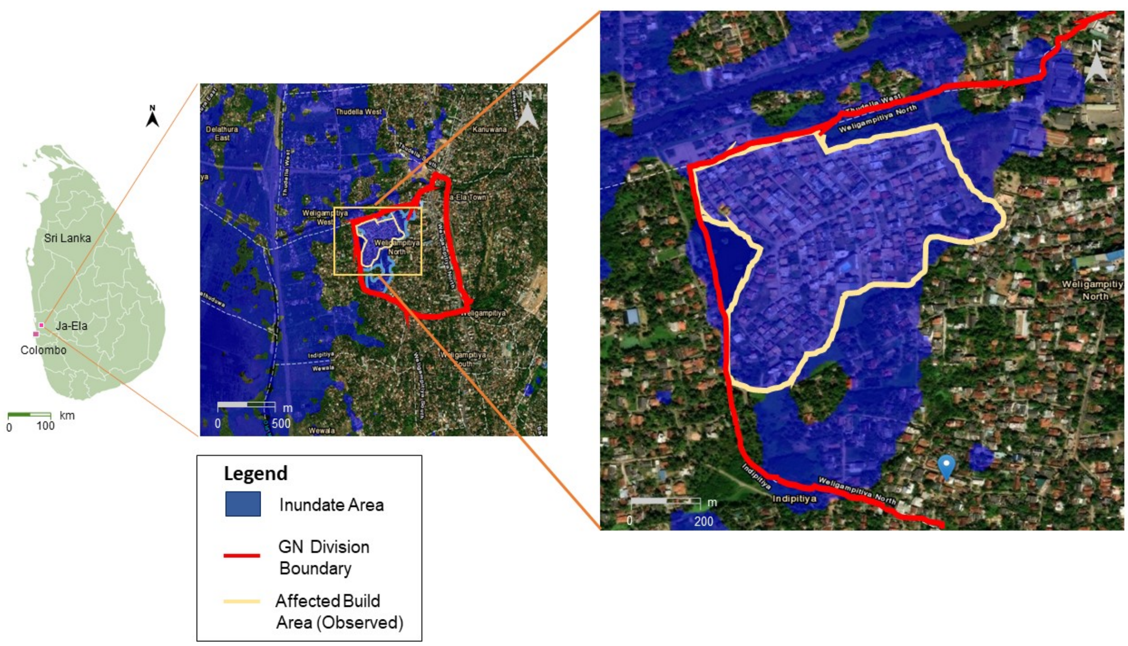

Figure 1 - Spatial analysis of the impacted built boundary within the Identified flash flood inundated area - Weligampitiya GND, Ja-Ela, Sri Lanka (Month of the image: October 2022)

In addition to that, the study area has inadequate stormwater drainage systems, bottleneck sections of drainage canals, blocked sea outfalls, reduced flow capacity due to aquatic growth and sedimentation, and decreasing water-retaining capacity due to land reclamation. Land development in the upstream basin also increases stormwater runoff. These factors also aggravate the flash flooding issues in the area, requiring urgent attention and mitigation strategies.

The flood inundation area data was obtained from the online subscription-based software called Flood Maps (Figure 1). From that source, the flash flood incident has resulted in a substantial risk to the land-used area, with approximately 31.6% of the total inundated landmass (0.12 km^2 out of 0.38 km^2) being directly impacted. This percentage highlights the significant vulnerability faced by the region, as nearly one-third of the area has been inundated by floodwaters.

Data and Data Collections

There was an effort made to collect both primary and secondary data. A photographic survey was conducted under the preliminary observations. Input data for the analysis and data on the intensity of the rainfall were gathered from secondary sources Metrological Department Sri Lanka primary and secondary data were further categorized under the special and non-special data for the analysis process.

Furthermore, interviews were carried out to collect the community's viewpoint on the potential danger of flash floods. The interviews, ranging from 45 minutes to 1 hour in duration, were conducted with a diverse range of individuals representing all categories, including residents and government officials such as Grama Niladhari, Disaster Management Centre (DMC) Ja-Ela and Gampaha, Irrigation Department engineers, Municipal Council Engineers, and the Disaster Manager from the DMC head office. This approach was taken to ensure the development of an impartial sample, and there were total of 35 complete interviews with the stakeholders listed above. Moreover, the interviewers were chosen based on their profound understanding and specialized skills in the domain of disaster management, as well as their specific roles in the research region. The interviews aimed to collect comprehensive information and insights from the interviewees regarding their encounters with disasters in the research region, together with their recommendations for efficient measures to prevent or alleviate the consequences of disasters. To guarantee the professionalism and accuracy of the survey findings, meticulous attention was given to the selection of interviewers and the design of the questionnaire. Subsequently, the facts gathered from these interviews underwent analysis and were utilized to formulate practical recommendations for enhancing disaster management in the designated region.

Data Analysis

Under this methodology, achieving the first objective involved a comprehensive approach to gathering and analysing data. An ArcGIS mapping technique was employed to organize and analyse the spatial data, providing a powerful tool for predicting land use patterns and determining peak stormwater discharge, which represents the non-flood hazard. To begin the study, the collected preliminary data from the photographic surveys were undertaken to gain a comprehensive understanding of the study area. Secondary sources were used to collect input data for the analysis and data on the intensity of rainfall. Both spatial and non-spatial data were analyzed using rational formulas. The land use pattern for the year 2030 was forecasted using data collected from the Ja Ela Municipal Council. The Municipal Council has conducted data analysis utilizing the Arc GIS mapping technique which provides valuable insights into the potential effects of urbanization and changes in land use on flood risk. This approach allowed for the visualization of land use patterns and their effects on stormwater runoff, providing an effective tool for decision-makers in disaster management. Hence, this approach allowed for a deeper understanding of the study area and its potential flood risk, providing valuable insights for improving disaster management strategies.

Achieving the second objective is primarily based on interviews with individuals who have direct involvement with government agencies at the subnational level in the planning and management of disasters, particularly in the context of flash flood risk adaptation. The interview questions focused on a range of topics, including issues and challenges related to flash flood risk adaptation, as well as potential strategies and suggestions for improvement. In addition to the interviews, the study drew on a variety of scholarly articles, government and international publications, local and international news sites, and websites to inform its analysis.

Then the final objective of the study entails proposing suggestions, which will be achieved by reviewing strategic plans, the relevant literature on best practices, and the analysis of adopted strategies from developed and developing countries. This approach aims to provide a comprehensive and evidence-based analysis, which will inform the development of effective strategies and plans for the management of the identified issue.

RESULTS AND DISCUSSION

Identifying the Risk

Upon analysis of the land use pattern concerning the data gathered from the Surveying department of Sri Lanka, it has been observed that the urbanized region has exhibited consistent and gradual growth. As a result of human-caused advancements in urban design, the number of water resources has decreased in the present day compared to 2015, and this tendency is anticipated to persist until 2030 (Figure 2). Furthermore, the reduction in agricultural lands and water bodies can be attributed to frequent land conversion for various purposes. These areas function as areas for the storage and accumulation of water. The anticipated outcome in 2030 would be an increase in the runoff volume. They highlighted the vital importance of implementing an adequate drainage infrastructure in Ja-Ela before 2030, to mitigate the potential hazards of sudden inundations and flash floods in Ja Ela Municipal Council (JMC).

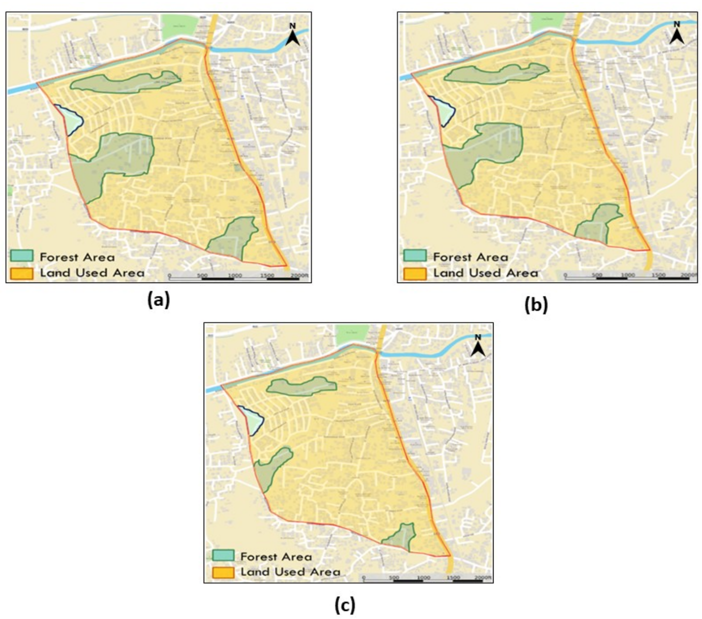

Figure 2: Maps showing (a) The land use pattern of 2015 (b) The land use pattern of 2020 and (c) The predicted land use Pattern of 2030 of Weligampitiya North GND (Developed by the author using the collected data from Surveying Department Sri Lanka)

Based on the hourly rainfall data spanning from 2000 to 2022 (Ja-Ela) extreme rainfall values in each year were calculated. Then by using the Gumble extreme value distribution method for an assumed storm duration of 2 hours, the rainfall intensity was observed to be 40 mmh^{-1} for a 50-year return period. The estimation was obtained by the use of an Intensity-Duration-Frequency (IDF) curve, which was generated in this study by analysing the rainfall data received from the Met department. The analysis took into consideration the return periods of 5, 50, and 100 years. The diagram is shown in (Figure 3).

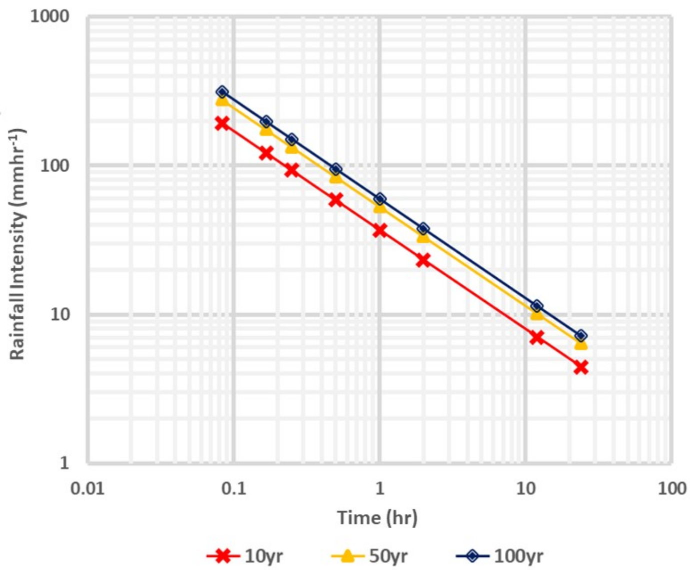

Figure 3: IDF Curve developed by the author based on rainfall data from the year 2000-2022 collected by the Met Department Ja-Ela

To precisely ascertain the runoff coefficient of the study area and determine the impact of flooding on susceptible regions, an analysis was conducted on various land use patterns including buildings, roads, and watershed layers. (Sonali & Sangasumana, 2018), found 35% paddy area and 37% home garden in their case study conducted in the Ja Ela area, with a runoff coefficient of the catchment area as 0.4 to 0.6. Subsequently, in this study under the preliminary studies the paved, agricultural, and construction areas were individually computed, considering the catchment area of 8.5 km^2. Therefore, by considering the individual areas, the average run-off coefficient was determined to be 0.77. Utilizing the rational equation, the maximum flow rate can be determined as 72.78 m^3s^{-1}. The basic flood runoffs in the Ja-Ela basin for probable 50-year rainstorm events under the future land use conditions are estimated for several base points along the river channel. And, in comparison with the estimated flood runoff, the basin retention is estimated. Respectively those values are 110 m^3s^{-1} (Depth - 2.38 m) and 70 m^3s^{-1} (Depth - 4.28 m). Therefore, considering flood runoff with the basin retention effect and calculated peak discharge, it shows the flood risk.

Flash Flood Mitigation Strategies by the Government, Public, and Individuals in Sri Lanka

Central Government - As per the Disaster Management Act, the primary responsibility for disaster management in Sri Lanka is vested with the national government. However, the organizational framework for disaster management is decentralized to lower levels, including provincial councils, local authorities, districts, divisions, and Grama Niladhari divisions. The Disaster Management Centre (DMC) is responsible for coordinating and implementing disaster management programs across the nation. This is achieved using a comprehensive Disaster Risk Management (DRM) mechanism that operates at a national level. Technical committees are designated to offer counsel on DRM undertakings at diverse levels, and sub-committees may also be designated for brief assignments. This text discusses the various stages involved in mitigating disaster risks and implementing effective management strategies. These stages include the creation of a National Centre for Risk Assessment, Data Collection, Research, and Analysis, as well as an Early Warning Centre that adheres to specific principles when issuing warnings. Hence, it is crucial to uphold efficient communication systems and collaborate with communities residing in regions susceptible to disasters.

Municipal Government - Making plans to construct flash flood protection structures. The study recommends a planning scale of a 50-year return period for the stormwater drainage plan in the Ja-Ela basin, which includes the main streams of Ja-Ela and Dandugam Oya (Figure 4).To ensure long-term flood protection, it is necessary to establish the maximum channel width for each mainstream in the potential urbanization areas. The proposed stormwater drainage plan for the Ja-Ela basin is as follows:

- Channel improvement of Ja-Ela with a total length of 7.0 km, with a width of 60 m from 2.0 km to 9.0 km.
- Channel improvement of Dandugam Oya with a total length of 9.9 km, with a width of 80 m from 3.5 km to 7.5 km and a width of 70 m from 7.5 km to 13.4 km.
- Storm water retention area with a total area of 876 ha, which includes 500 ha for lower retention areas and 376 ha for upper retention areas.

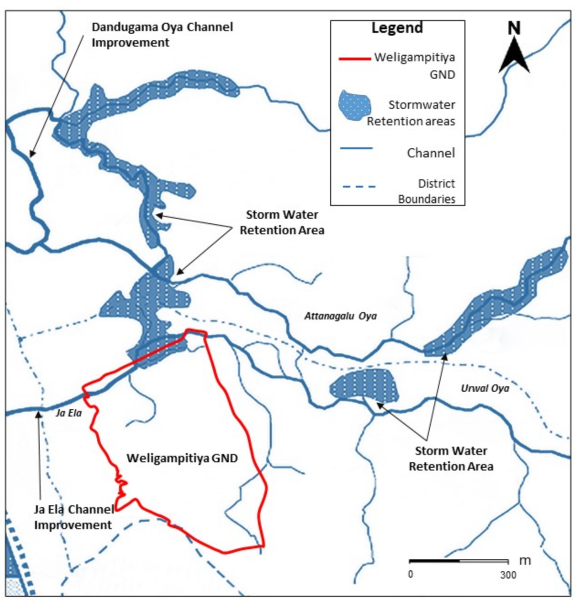

Figure 4 - The Storm water Drainage Plan in the Ja-Ela Basin (2021) developed based on the data of the Municipal Council – Ja-Ela

Community - In the study area, flash floods have direct consequences such as submerging houses, damaging physical assets, and posing risks associated with rising water levels. Based on the field study conducted on a sample of 25 houses showed that 8% of the respondents reported collapsed houses due to flash floods, while the remaining 92% experienced significant damages that required substantial repair costs. Among those houses affected by recurrent flash floods and living in low-lying areas, 4% relocated their homes to adjacent highlands. The remaining 96% either adapted to the floods or raised their settlements to prevent flooding, except during major flood events. Some of them 96% built their homeland fully enclosed with high walls and gates (Figure 5).

Figure 5: Flood protection measures -entrance elevated barriers and fully covered walls (Date of the image:(September 2022)

Table 1: Comparison of Flash Flood Mitigation Strategies between Sri Lanka and Other Developed andDeveloping Countries.

Mitigation Strategy	Sri Lanka	Other Country	Comparison
Real-time flood inundation mapping and notification systems	DMC - Real-time flood mapping and warning system with SMS, radio, TV, and social media notifications.[Male-Director(Early Warning) c.d.,DMC,45yrs,Jan 2023]	Netherlands:"Room for the River" program (Room for the River, 2019)	Room for the River" program focused more on creating more space for rivers to prevent flooding, using a holistic approach including infrastructure projects, spatial planning, and community engagement that yields more enduring and sustainable solutions compared to real-time flood mapping.
Regional-level remedy	DMC partners with CAFFG for real-time flash flood data using satellite rainfall and on-site observations. [Male-	US: National Weather Service(NWS) provides flood	NWS in the United States utilizes not only satellite and ground observations but also

	Director (Early Warning) c.d., DMC,45yrs, Jan. 2023]	warnings using radar, satellite, and ground observations.(National Weather Service)	radar to provide flood warnings at the national level which covers a large expanse and offers a more precise solution.
Community education and awareness	DMC - conducted educational programs targeting children, teachers, and communities [Male- Divisional disaster management officer- Gampaha DMC, 39yrs, March- 2023]	Japan:"Community-Based Disaster Risk Reduction (CBDRR)" program. (Ikeda, S., Araki, T., & Han, Y. (2021))	CBDRR community-focused strategy leads to amore efficient and stable reduction of catastrophe risks compared to general community awareness sessions.
Involvement of all stakeholders	NBRO - Develops and implements flood mitigation plans and conducts research on flood management strategies.(NBRO)	Thailand: Department of Water Resources - Collaborates for flood mitigation plans, research, and training (ONWR, 2013)	The NBRO offers a decentring structure, whereas the Thailand Department of Water Resources exhibits a more organised and centred approach.
Structural measures	Implemented structural measures such as the construction of flood walls, riverbank stabilization, and river training. (Mahaweli Authority of Sri Lanka)	UK: Flood and Coastal Erosion Risk Management Strategy. (Environment Agency, 2020)	The UK strategy is likely to include a national-level approach that addresses various measures, policies, and plans to manage both flood and coastal erosion risks comprehensively.

As mentioned in (Table 1) in Sri Lanka, the DMC and NBRO play important roles in the implementation of flood mitigation plans. The DMC's real-time flood mapping and warning system, as well as its partnership with the CAFFG, provide valuable information for decision-makers and the public. Community education programs and structural measures such as flood walls and the Mahaweli River Flood Protection Scheme also contribute to Sri Lanka's flood mitigation strategies.

Other countries such as the Netherlands, the United States, Japan, Thailand, and the United Kingdom also employ a variety of flood mitigation strategies. The Netherlands' "Room for the River" program, the US NWS flood warning system, and Japan's "Community-Based Disaster Risk Reduction" program are notable examples. These countries also prioritize community involvement, stakeholder collaboration, structural measures such as the construction of flood walls, dams, and retention basins, and natural flood management measures.

CONCLUSION

The analysis of land use patterns revealed a concerning trend of urbanization, resulting in reduced water resources and agricultural lands, which contribute to increased runoff volume and flash flood risks. It is crucial to prioritize the implementation of adequate drainage infrastructure in vulnerable areas like Ja-Ela before 2030 to mitigate potential hazards effectively.

By examining rainfall data and conducting calculations, the study estimated peak discharge and flood runoffs in the Ja-Ela basin, emphasizing the existing flood risk. These findings underscore the urgent need for robust strategies to minimize the impact of flash floods. At the government level, the Disaster Management Centre (DMC) plays a central role in coordinating and implementing disaster management programs in Sri Lanka. Establishing efficient communication systems and fostering collaboration with communities residing in vulnerable regions are essential components of successful mitigation efforts.

Municipal governments should prioritize the construction of flash flood protection structures, such as channel improvements and stormwater retention areas, to ensure long-term flood protection. These measures can significantly reduce the impact of flash floods and protect both lives and infrastructure. Within communities, it was observed that flash floods directly affect houses and physical assets. Respondents employed various adaptation measures, including raising their settlements or constructing protective barriers. Community involvement, education programs, and the integration of structural and non-structural measures are crucial for effective flood mitigation strategies.

Compared with Sri Lanka, it is evident that successful flood mitigation strategies in other countries incorporate community participation, stakeholder collaboration, and a combination of structural and natural management measures. Examples from the Netherlands, the United States, and Japan demonstrate the importance of involving communities, employing early warning systems, and implementing comprehensive risk reduction programs.

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Growth and Yield Performances of Cabbage Grown under a Protected House in Low Country Wet Zone of Sri Lanka as Affected by Artificial Lights and Rate of Albert Fertilizer

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ABSTRACT

A study was conducted in two automated protected houses at Faculty of Agriculture, University of Ruhuna, Sri Lanka to investigate the effect of artificial light supplementation (using LED light source) and rate of Albert fertilizer on growth and yield of Cabbage. The experiment was conducted in a two-factor factorial (2 x 2) Completely Randomized Design with five replicates. The tested two factors were light (with and without artificial lights) and rate of Albert fertilizer (1.0 g/plant/day and 2.0 g/plant/day). These two fertilizer rates were selected based on the best performed fertilizer rates, reported in a previous study. Thus, present study aims to find the effect of previously selected two fertilizer rates and artificial lights on growth and yield of Cabbage. Growth and yield parameters were measured and collected data were analyzed using ANOVA. Subsequently, means were separated by least significant difference (LSD) at 5% probability level. Results revealed that there is no interaction effect between rate of fertilizer and artificial lights on growth or yield parameters of cabbage. However, both growth and yield parameters of cabbage were significantly affected at least by one main factor. Plant height and canopy diameter were significantly increased by artificial lights. Significantly highest number of loose leaves per plant was recorded by 2.0 g/plant/day. 1.0 g/plant/day fertilizer rate and artificial lights recorded significantly highest total above ground biomass yield, cabbage head weight and head perimeter. Therefore, greater yields from cabbage can be obtained by applying Albert fertilizer 1.0 g/plant/day and artificial light enhanced the yield of cabbage.

Key words: Albert fertilizer, artificial light, automated protected house, Cabbage

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INTRODUCTION

Cabbage (*Brassica oleracea* L.) is one of the most vital and nutritious vegetables belonging to the family Brassicaceae. Due to its nutritional value and delicious taste, cabbage was highly popular and it was extensively grown in hill country of Sri Lanka as a year-round crop (Pavithira, 2022). Nowadays, cabbage is growing in low country of Sri Lanka with promising yields (Perera *et al*., 2023). According to Pavithira (2022), cabbage can be successfully grown in protected houses by manipulating the climatic conditions at their optimum levels (Pavithira, 2022).

Light is essential to plant life and it determines the photosynthetic rate (Avercheva *et al*., 2009). Many stages of plant growth are significantly influenced by light. Additionally, it serves as the cornerstone of a plant's energy metabolism. When there is insufficient light for plant growth, the capacity of plants to absorb and assimilate CO_2 declines. As a result, there are fewer photosynthetic products produced, which eventually results in slower crop growth (Wang *et al.,* 2021). Zervoudakis *et al*. (2012) mentioned that solar radiation is the most important environmental component that controls photosynthesis and, as a result, the survival, growth, and adaptation of plants. Furthermore, they stated that in any ecosystem, light intensity fluctuates geographically and over time (diurnally and seasonally), having an impact on plant development and yield. Although numerous studies have been conducted to determine the ideal light intensity for plant growth, there are still studies that need to be conducted on crop specific and location specific.

Although natural light is frequently utilized in agriculture, it has the disadvantage of being easily diverted by fog, clouds, or even the cover of the greenhouse. Consequently, production of biomass by plants in natural light might be unpredictable (Saapilin *et al*., 2022). In Sri Lanka the sky in the wet zone is overcast and cloudy on most days of the year restricting adequate sun light penetration to the ground (The morning, 2020). Therefore, application of artificial lights for crop production where natural light is insufficient could be helpful to obtain maximum crop productivity.

Moreover, Both (2000) stated that when the amount of light provided by sunshine falls short of the necessary amount, the difference can be made up using an additional lighting system. It is possible to control such a lighting system only with the aid of computer software to provide precisely the same amount of light every day of the year. Recent software advancements have made it possible for the computer to maintain track of the amount of light received since dawn. The computer decides when to activate the lighting system by comparing the received light to the required amount of light (Both, 2000).

Light-emitting diodes (LEDs) are the most appropriate artificial light source because they can produce a precise spectrum with close illumination, a constant spectrum distribution, and higher photosynthetically active radiation (PAR) efficiency for favorable crop production. Numerous studies have shown that LEDs can positively increase crop yield, initiate the synthesis of specific metabolites, and improve fruit and vegetable quality (Saapilin *et al*., 2022).

In addition, it is essential to enhance nutrient usage efficiency by comprehending how fertilizer affects crop development and yield performances. The knowledge on optimum fertilizer amount on the growth and yield of cabbage grown under artificial light condition is still lacking. Therefore, this research was conducted to evaluate the effect of artificial lights and rate of Albert fertilizer on growth and yield performances of cabbage grown in protected houses in low country wet zone of Sri Lanka.

MATERIALS AND METHODS

This study was conducted in two automated protected houses at Faculty of Agriculture, University of Ruhuna, Sri Lanka to investigate the effect of artificial light supplementation on growth and yield of cabbage for the best performed fertilizer rates found in a previous research. Therefore, 1.0 g/plant/day and 2.0 g/plant/day fertilizer treatments and two levels of artificial light (with artificial lights and without artificial lights) were used for the current study. Artificial lights were fixed in one protected house. Therefore, two levels of artificial light were used in two protected houses providing two fertilizer levels for both protected houses.

Uniform cabbage (Var: Green Coronet) plants were transplanted in coco peat grow bags as one plant per bag after 28 days of nursery period. They were placed on the floor of the protected house with the spacing of 40 x 50 cm (DOA). The experimental design was two-factor factorial (2 x 2) Completely Randomized Design with five replicates. The tested two factors were light; L_0 (without artificial lights), L_1 (with artificial lights) and rate of Albert fertilizer; R_1 (1.0 g/plant/day), R_2 (2.0 g/plant/day). Treatments were applied daily.LEDs (60 W) of white colour were used for artificial light supplementation and they were placed 1 foot above the crop canopy. LEDs were automatically turned on when the lux level inside the protected house became less than 3000 lux from 6.00 a.m. to 6.00 p.m. Additionally, they were automatically turned off when the lux level inside the protected house became greater than 3000 lux from 6.00 a.m. to 6.00 p.m. Therefore, a minimum level of 3000 lux was maintained inside the protected house from 6.00 a.m. to 6.00 p.m. through IoT (Internet of Things) based automation system. During the night time from 6.00 p.m. to 6.00 a.m., no artificial light was supplied to facilitate the dark reaction of photosynthesis.

Two rates of Albert fertilizer solutions were prepared and they were applied to plants at one time per day. 200 ml of Albert fertilizer solution with 1.0 g and 2.0 g concentrations as assigned in two treatments was applied each plant per day. After application of fertilizer, 800 ml of water/plant/day as three splits was applied via drip irrigation system as 300 ml of water at 8.00 a.m., 300 ml of water at 11.00 a.m. and balance 200 ml of water applied at 2.00 p.m. Management of pests and diseases were done according to the recommendations of the Department of Agriculture, Sri Lanka (DOA). Harvesting was done 90 days after transplanting (DOA).

As growth parameters; plant height, number of loose leaves per plant and canopy diameter were measured at two weeks interval. As yield parameters total above ground biomass yield, fresh weight of head and perimeter of head were measured at harvesting after 90 days from transplanting. Collected data were statistically analyzed using Analysis of Variance (ANOVA) from Statistical Analysis System (SAS) 9.1.3 version. Subsequently, means were separated from Least Significant Difference Test (LSD) at 5% probability level.

RESULTS AND DISCUSSION

Results revealed that there is no interaction effect between rate of fertilizer and artificial lights on growth and yield parameters of cabbage. However, both growth and yield parameters of cabbage were significantly affected at least by one main factor. Results show that the plant height and canopy diameter were significantly influenced by artificial lights. Significantly highest values for these parameters were recorded with artificial lights. Significantly highest number of loose leaves per plant was recorded by 2.0 g/plant/day. Total above ground and head perimeter were significantly affected by main factors individually. 1.0 g/plant/day fertilizer rate and use of artificial lights recorded significantly highest total above ground biomass yield, cabbage head weight and head perimeter.

Plant Height

Significantly higher ($p < 0.05$) plant height was recorded when artificial lights were used (Figure 1) than without artificial lights from 4th week after transplanting to end of the crop. Several other researchers also recorded higher plant height under artificial light supplementation over natural light. Cavallaro and Muleo (2022) stated that stem elongation of crop plants is a growth and development function of the control activity of light. Sutulienė *et al*. (2022) recorded significantly taller basil and lettuce plants under 150 and 250 µmol m^{-2} s^{-1} with compared to the plants cultivated in natural light. Nguyen *et al*. (2019) also observed that increasing plant height with increasing light intensity of spinach plants when red and blue LED lights are used in conjunction. Environmental conditions have a profound influence on the growth and development of plants. Light intensity is the most important of growth and development of a plant (Nguyen *et al*., 2019). Therefore, supplementation of artificial lights during inadequate natural light conditions may support plant growth.

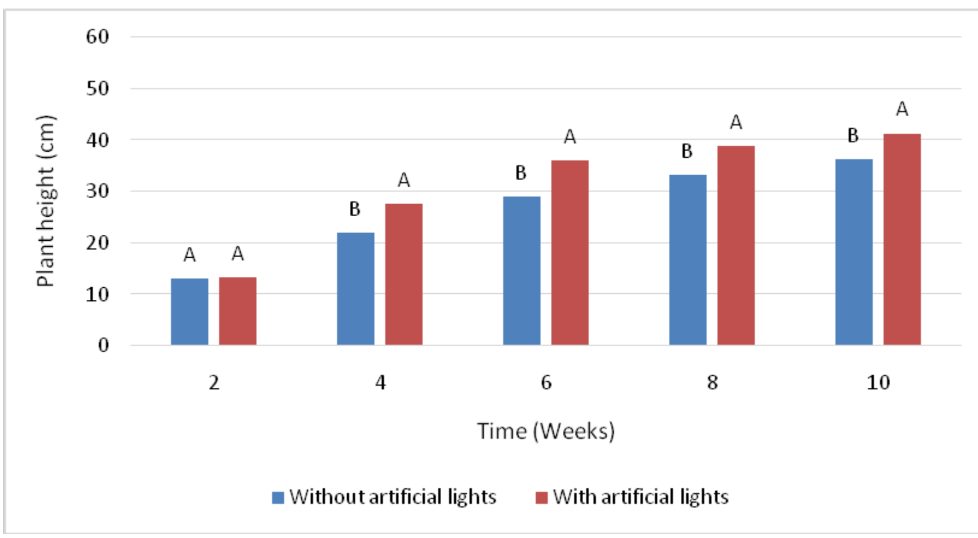

Figure 1: Mean plant height of cabbage plants during crop growth and harvesting as affected by artificial lights

Canopy Diameter

Canopy diameter of cabbage plants was significantly affected by artificial lights. Significantly higher ($p < 0.05$) canopy diameter was recorded with artificial lights (Figure 2) than without artificial lights from 4th week after transplanting onwards. Saapilin *et al*. (2022) recorded higher growth rate of Chinese cabbage (*Brassica rapa* var. chinensis) plants in high light intensity than plants grown in low light intensity. They reported unequal leaf distribution in plants grown under natural light conditions as a result of the variable light intensity received by cabbage plants during the day. With contrast to these plants, cabbage plants grown under constant artificial lights resulted consistently grown leaves across the crown. He *et al.* (2019) resulted rapid leaf area development in Chinese broccoli cultivated under red(R) : blue(B) -LED ratio of 84:16. Therefore, artificial light supplementation can increase leaf area which then leads to higher canopy diameter of plants in Brassicaceae family. Hence, providing artificial lights as a complement to natural light conditions may boost plant growth.

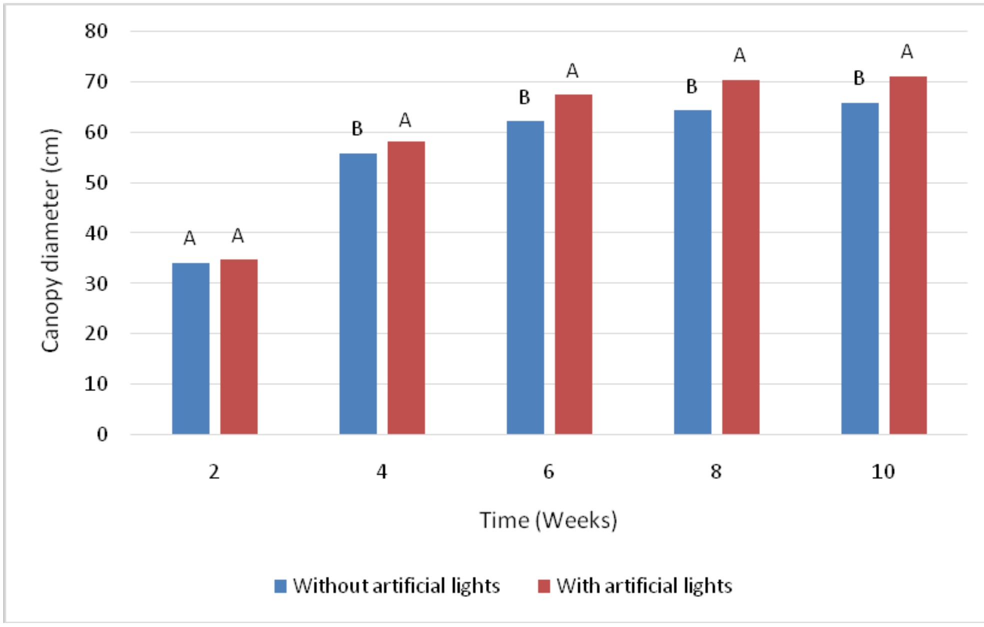

Figure 2: Mean canopy diameter of cabbage plants during crop growth and harvesting as affected by artificial lights

Number of Loose Leaves per Plant

Number of loose leaves per plant was significantly affected by rate of fertilizer. Significantly higher ($p < 0.05$) number of loose leaves per plant was recorded by application of 2.0 g of fertilizer /plant/day (Figure 3) over 1.0 g of fertilizer /plant/day from 8th week after transplanting to harvest. According to Laczi *et al*. (2016), number of leaves in cabbage is a crucial parameter since their function in light absorption affects transpiration, photosynthesis, and crop yield. They observed significantly increased number of leaves by application of horse manure under protected conditions where low values were achieved by unfertilized cabbage plants. In addition, as cited by them Easmin *et al*. (2013) reported that the amount of fertilizer used directly affected the number of leaves on Chinese cabbage. They applied 0, 160, 200, and 250 kg N/ha, and the number of leaves increased steadily with nitrogen fertilizer application. In 250 kg N/ha, they obtained 55.51 leaves of Chinese cabbage, which was the significantly highest. In that experiment, the application of 200 kg N/ha and 160 kg N/ha produced statistically same results, which were lower than the results of 250 kg N/ha. The lowest number of Chinese cabbage leaves (42.96) was recorded at 0 kg N/ha. Therefore, results of the present experiment are in agreement with past findings which the number of loose leaves in cabbage plants is directly affected by the amount of fertilizer applied.

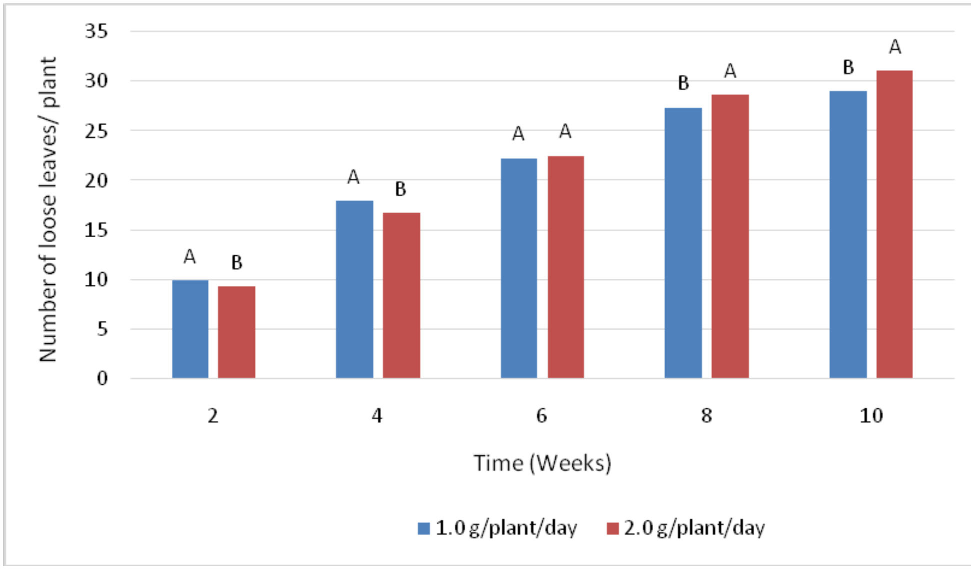

Figure 3: Mean number of loose leaves per cabbage plant at different weeks after transplanting as affected by rate of fertilizer

Fresh Weight of Heads

There was no interaction effect on fertilizer rates and artificial light but fresh weight of cabbage heads was significantly affected by main factors separately. 1.0 g/plant/day fertilizer rate and artificial lights application recorded significantly highest ($p < 0.05$) fresh weight of heads (Figure 4 and 5). The significantly highest fresh weight of cabbage heads was recorded in 1.0 g/plant/day fertilizer rate than 2.0 g/plant/day fertilizer rate. Although previous research have revealed that increased amounts of fertilizer resulted larger cabbage heads (Kumar and Rawat, 2002; Pramanik, 2007; Choudhary *et al*., 2009; Tehulie and Belete, 2021), in the present experiment significantly highest cabbage head weight was recorded in the lowest amount of fertilizer. That might be due to the high temperature in low country where cabbage was grown. The temperature in low country was not optimum for better cabbage head development.

However, artificial supplementation of light has significantly improved crop yield where natural light is not adequate. According to Saapilin *et al*. (2022), artificial light could increase the effectiveness of Chinese cabbage production. Yasoda *et al*. (2018) reported no curd formation in cauliflower grown in dry zone of Sri Lanka under 75 % shade level and they stated that it might be due to the inadequate light intensity and subsequently low photosynthetic activity. In addition, Sutulienė *et al*. (2022) reported the fresh and dry weight of basil plants cultivated in the growth chamber increased with illumination intensities of 50, 150, 300, and 600 $\mu molm^{-2}s^{-1}$. Additionally, they claimed that when considering the environmental aspects in agriculture, the two most essential elements for plant growth are light and nutrition. In addition, light intensity has a direct impact on plant metabolism and development. Furthermore, as mentioned by them although additional lighting may be required in greenhouses to enhance plant growth, it is only necessary when the daily light integral is naturally low. Therefore, maintaining a minimum lux level of 3000 lux from 6.00 a.m. to 6.00 p.m. was supportive to enhance cabbage head yield where natural sunlight was not sufficient.

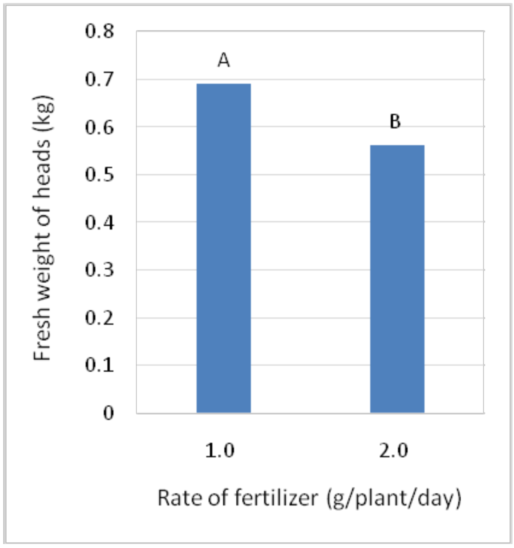

Figure 4: Mean fresh weight of cabbage heads as affected by rate of fertilizer

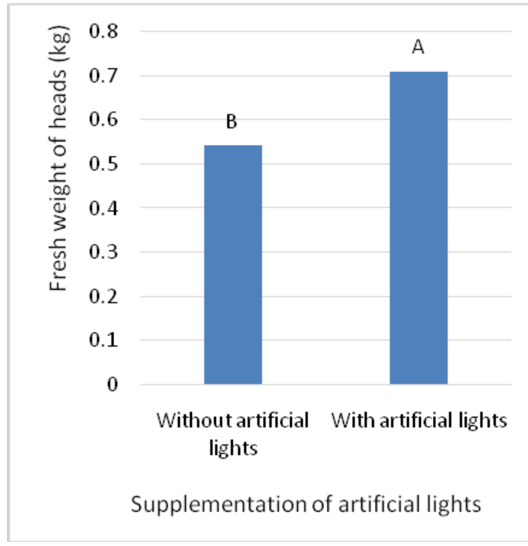

Figure 5: Mean fresh weight of cabbage heads as affected by artificial lights

Perimeter of Head

Perimeter of cabbage heads was also significantly affected by main factors separately. 1.0 g/plant/day fertilizer rate and artificial lights application recorded significantly highest ($p < 0.05$) perimeter of head (Figure 6 and 7).

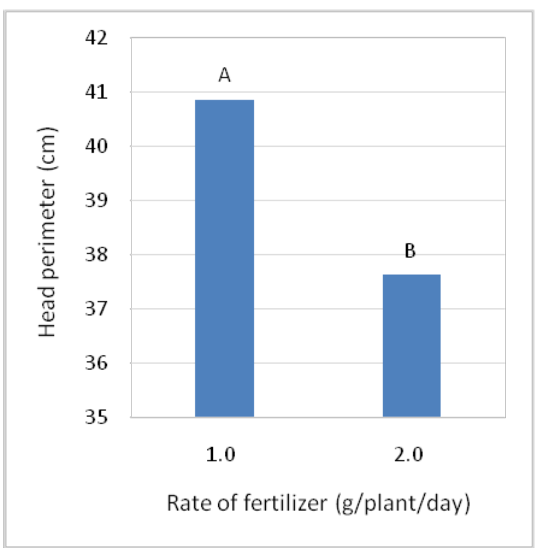

Figure 6: Mean perimeter of cabbage heads as affected by rate of fertilizer

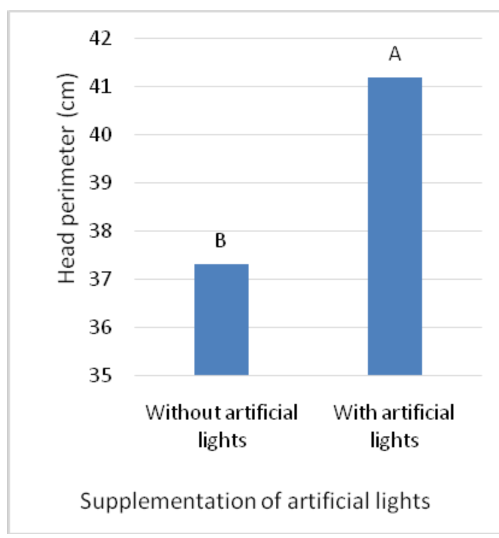

Figure 7: Mean perimeter of cabbage heads as affected by

Total Above Ground Biomass Yield

Total above ground biomass yield was significantly affected by main factors separately. 1.0 g/plant/day fertilizer rate and artificial lights application recorded significantly highest ($p < 0.05$) total above ground biomass yield (Figure 8 and 9). The growth rate and biomass of Chinese cabbage plants cultivated in high light intensity were higher than those cultivated in low light intensity (Saapilin *et al*., 2022). Similar results were observed by Duc *et al*. (2021), who also stated that protected growing facilities with the lighting conditions showed high production capacity of Chinese cabbage grown in a plant factory. Jones-Baumgardt *et al*. (2019) reported increment in fresh weight by 36% in cabbage microgreens from 100 to 600 mmol/m^2/s light intensity increment. In addition, Proietti *et al*. (2021) reported that continuous lighting in controlled environment enhanced the total fresh biomass of rocket plants (*Eruca vesicaria)*. Even though natural light is mostly utilized in agriculture, it has the drawback of being readily diverted by fog, clouds, and even greenhouse covers. Consequently, biomass generation by plants in natural light might be unpredictable (Saapilin *et al*., 2022). As well, even Sri Lanka is close to the equator, the sky in the wet zone in Sri Lanka is overcast and cloudy on most days in rainy season of the year restricting adequate sun light penetration to the canopy (The morning, 2020). Therefore, application of artificial lights for crop production where natural light is insufficient could be resulted promising yields. When considering the rate of fertilizer, 1.0 g/plant/day fertilizer application resulted significantly higher total above ground biomass yield than 2.0 g/plant/day fertilizer application. That might be attributed with greater head yields obtained from 1.0 g/plant/day fertilizer rate over 2.0 g/plant/day fertilizer rate which ultimately resulted a higher total above ground biomass yield by 1.0 g/plant/day fertilizer applied plants.

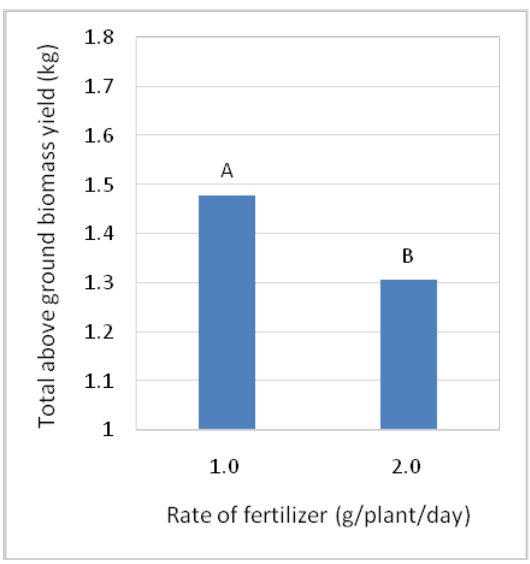

Figure 8: Mean total above ground biomass yield as affected by rate of fertilizer

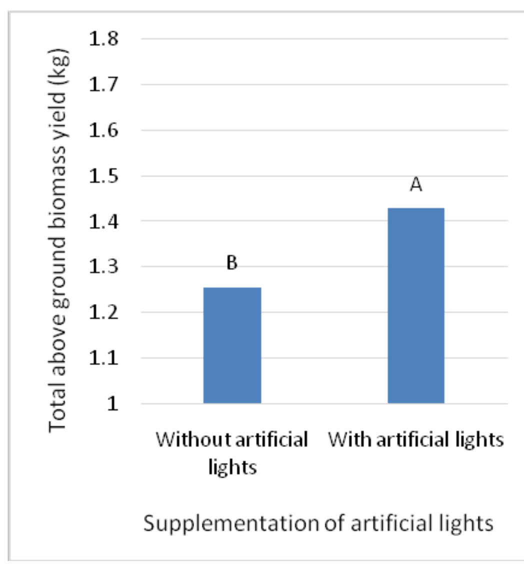

Figure 9: Mean total above ground biomass yield as affected by artificial lights

CONCLUSION

Cabbage head yield was increased when Albert fertilizer applied 1.0 g/plant/day. In addition, supplementary artificial lights enhanced growth parameters of cabbage which then helped to increase head yields. Therefore, greater yields from cabbage can be obtained by applying Albert fertilizer 1.0 g/plant/day and providing artificial lights under protected house conditions in low country wet zone of Sri Lanka.

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   - Introduction: Justification of the research work, objectives and hypotheses should be included in the introduction.
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   - Conclusions: Should be concise.
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   - All acronyms should be written in full at the first time of appearance. Abbreviations can be used subsequently.
   - The full stop should not be included in abbreviations. Where abbreviations are likely to cause ambiguity or may not be readily understood by readers, the units should be mentioned in full.
9. On being informed of the acceptance, the manuscripts should be revised as per the reviewers' suggestions and re-submitted to the Editor – SLAAS. The accepted manuscripts will be published in the inaugural Journal of the SLAAS. Manuscripts that do not confirm to the above guidelines will not be accepted.
10. Acknowledgements Only the essential individuals and/or organizations/institutes should be include 11. Need to attach the manuscripts both as 1. with names and affiliations of the author and 2. Without with names and affiliations of the author

ISSN 1391-0256

Journal of the Sri Lanka Association for the Advancement of Science

Volume 6 Issue 2

Contents

Research Article

Identification of the Adaptation Strategies to Mitigate Flash Flood Risk in Sri Lanka – Case Study in Ja-Ela

W A U D Perera, N K N M Nakkawita, H P A M Siriwardana, R S M Samarasekara

Growth and Yield Performances of Cabbage Grown under a Protected House in Low Country Wet Zone of Sri Lanka as Affected by Artificial Lights and Rate of Albert Fertilizer

U D T Perera , S Subasinghe, K K L B Adikaram, H K M S Kumarasinghe, M K D K Piyaratne

9771391025002

Edited and Published by the Sri Lanka Association of for the Advancement of Science

e-ISSN 2682-6992