EFFECTS OF MEDIA MIXTURES FROM SELECTED AGRICULTURAL WASTES TO INCREASE NUTRIENT UPTAKE EFFICIENCY, GROWTH AND YIELD PERFORMANCE OF CHILLI UNDER FERTIGATION SYSTEM

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

June 2023

FP 2023 24

DEDICATION

This research study is dedicated to all scientists, researcher and lecturer around the world who are struggles to keep the sanctity of our earth's atmosphere preserved. For my great and very helpful supervisor Associate Professor Dr. Susilawati Kasim, the guidance and support you give throughout my study period is priceless. For my beloved parents, Amran bin Mohammed Bahari (father) and Normariani binti Abd. Malek (mother), this thesis is dedicated for both of you, the cost of bring me up until this level is incalculable.

Thank you, Allah,

&

May Allah rewards all of you

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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June 2023

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In contemporary agricultural practices, the efficient utilization of resources and the development of sustainable cultivation methods are imperative for ensuring food security and environmental stewardship. The ever-growing global population places substantial pressure on agriculture to enhance productivity while minimizing the ecological footprint. In this context, the integration of innovative approaches becomes crucial, especially in optimizing nutrient management for crop production. Agricultural wastes, often considered as byproducts of farming activities, present a promising avenue for sustainable resource utilization. These materials possess inherent nutrient content, and their incorporation into media mixtures has the potential to enhance soil fertility, nutrient uptake efficiency, and subsequently, the growth and yield performance of crops. Fertigation, the application of fertilizers through irrigation systems, offers a practical and efficient means of delivering nutrients directly to the root zone, further maximizing their utilization by plants.

This study focuses on exploring the effects of media mixtures derived from selected agricultural wastes on the nutrient uptake efficiency, growth, and yield performance of chilli (*Capsicum annuum* L.) under a fertigation system. Furthermore, the study was conducted to identify the beneficial use of mixtures of agricultural waste materials in minimizing fertilizer consumption in *Capsicum annuum* production in fertigation system and evaluate the cost-benefit of different mixtures of agricultural waste materials under fertigation system. Nine different growth media mixtures (v/v) were prepared by using CCD, coconut shell ash (CSA), and palm kernel shell biochar (PKSB) and there were designated as T1 (100% CCD), T2 (100% CSA), T3 (100% PKSB), T4 (3 CCD:1 CSA), T5 (2 CCD:1 CSA), T6 (1 CCD:1 CSA), T7 (3 CCD:1 PKSB:), T8 (2 CCD:1 PKSB), T9 (1 CCD:1 PKSB).The growth media mixtures were analyzed for their physio- chemical properties using standard protocols. The experimental were arranged by completely randomized design (CRD) with three replicates. The parameter of physio- chemical properties analysis such as particle size, bulk density, particle density and porosity, water retention, pH value, electrical conductivity, cation-exchange capacity and exchangeable, cation K, Ca, Mg, Na, nutrient content and nutrient retention. Then, a field trial under fertigation system was conducted using the growth media mixtures to investigate their effects on the growth performance and yield of *Capsicum annuum L. Var. Kulai*. This experiment was conducted as two-factorial split plot design and the samples were arranged in a randomized complete block design (RCBD) with three blocks. Media analysis such as pH and electrical conductivity, total organic carbon, nitrogen, and sulfur, cation exchangeable capacity and exchangeable cations nutrient content, meanwhile plant growth characteristics, root size, dry matter, and nutrient content of fruit were measured in this experiment. The results showed that T2 has a potential to be a liming agent. The organic fertilizer and soil fertility enhancer due to contain high pH (7.89), electrical conductivity (2.70dS/m), cation-exchangeable capacity (12.57cmolc/kg), nutrient retention and total nutrients content of N (0.58%), P(13.90mg/l), and K(191.70mg/l). However, T2 is lack in aeration and water retention due to low in porosity (24.3%). The findings in second study were T1 in 100% fertilizer rate able to enhance the growth and production of *Capsicum annuum L. Var. Kulai* in 4 months by improved the plant height (57.0cm), total leave area (3668.36 cm^2), chlorophyll content (64.0), number (58) and weight of yields (1008g) of *Capsicum annuum L. Var. Kulai* in standard fertilizer rate due to reached the optimum balance condition in pH (5.58)) and cation-exchangeable capacity (15.64 cmolc/kg) in growth media. In third study, T2 showed the promising outcomes as its able to promoting the growth and production of *Capsicum annuum L. Var. Kulai* in 4 months by gave the better result in plant height (62.0cm), total leave area (3807.88cm^2), chlorophyll content (66.2), weight of yields (1115g) in reducing 50% of fertilizer rate. T2 also enhances the water and nutrient uptake by promoting root diameter (1.73mm), root surface area (267.60cm^2), and root volume (10.66cm^3) of *Capsicum annuum L. Var. Kulai*. Moreover, T5 and T7 also improve the plant growth and production of *Capsicum annuum L. Var. Kulai* in 50% fertilizer rates due to high water and nutrient retention, porosity, and cation- exchangeable capacity level. The growth media T2 and T5 are more profitable and resultant in high rate of benefit cost since its able to increase the plant production, and reduce the raw material and fertilizer cost. This

finding recommends the farmer to use the formulation of growth media T2 and T5 that improve the nutrient use efficiency by promoting the plant performance of *Capsicum annuum L. Var. Kulai*, and minimize the fertilizer use.

Keywords: Agricultural Waste, Field Trial, Media Analysis, Coconut Coir-Dust, Coconut Shell Ash, Palm Kernel Shell Biochar.

SDG: GOAL 4: Quality Education, GOAL 12: Responsible Consumption and Production, GOAL 15: Life on Land

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KESAN CAMPURAN MEDIA DARIPADA SISA PERTANIAN TERPILIH UNTUK MENINGKATKAN KECEKAPAN PENGAMBILAN NUTRIEN, PERTUMBUHAN DAN PRESTASI HASIL CILI DI BAWAH SISTEM FERTIGASI

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Dalam amalan pertanian kontemporari, pemanfaatan sumber daya dengan cekap dan pembangunan kaedah penanaman yang mampan adalah penting untuk memastikan keselamatan makanan dan tanggungjawab alam sekitar. Tekanan yang semakin meningkat daripada penduduk global menempatkan tekanan besar ke atas pertanian untuk meningkatkan produktiviti sambil meminimumkan jejak ekologi. Dalam konteks ini, integrasi pendekatan inovatif menjadi penting, terutamanya dalam mengoptimumkan pengurusan nutrien untuk pengeluaran tanaman. Sisa pertanian, yang sering dianggap sebagai hasil sampingan aktiviti pertanian, menyajikan laluan yang menjanjikan untuk pemanfaatan sumber secara mampan. Bahan-bahan ini mempunyai kandungan nutrien asli, dan penyatuan mereka ke dalam campuran media mempunyai potensi untuk meningkatkan kesuburan tanah, kecekapan penyerapan nutrien, dan seterusnya, pertumbuhan dan prestasi hasil tanaman. Fertigasi, aplikasi baja melalui sistem pengairan, menawarkan cara

praktikal dan cekap untuk menyampaikan nutrien terus kepada zon akar, meningkatkan penggunaannya oleh tanaman. Kajian ini memberi tumpuan kepada meneroka kesan campuran media yang berasal dari sisa pertanian terpilih terhadap kecekapan penyerapan nutrien, pertumbuhan, dan prestasi hasil cili (*Capsicum annuum L.)* di bawah sistem fertigasi. Dengan menilai impak campuran media ini, kami bertujuan untuk menyumbang pandangan berharga ke dalam amalan pertanian mampan yang tidak hanya mendaur ulang bahan buangan pertanian tetapi juga mengoptimumkan ketersediaan nutrien untuk hasil tanaman yang lebih baik. Penyelidikan ini diletakkan di persimpangan antara kecekapan sumber, kelestarian alam sekitar, dan produktiviti pertanian, menangani keperluan mendesak untuk penyelesaian inovatif bagi menangani cabaran pertanian moden. Tambahan pula, kajian dijalankan untuk mengenal pasti penggunaan berfaedah campuran bahan buangan pertanian dalam meminimumkan penggunaan baja dalam pengeluaran *Capsicum annuum* dalam sistem fertigasi dan menilai kos-faedah campuran berbeza bahan buangan pertanian di bawah sistem fertigasi. Sembilan campuran media pertumbuhan berbeza (v/v) telah disediakan dengan menggunakan CCD, abu tempurung kelapa (CSA), dan biochar tempurung isirong sawit (PKSB) dan telah ditetapkan sebagai T1 (100% CCD), T2 (100% CSA), T3 (100% PKSB), T4 (3 CCD:1 CSA), T5 (2 CCD:1 CSA), T6 (1 CCD:1 CSA), T7 (3 CCD:1 PKSB:), T8 (2 CCD:1 PKSB), T9 (1 CCD:1 PKSB). Campuran media pertumbuhan dianalisis untuk sifat fisio-kimianya menggunakan protokol piawai. Percubaan telah disusun dengan reka bentuk rawak sepenuhnya (CRD) dengan tiga ulangan. Parameter analisis sifat fisio-kimia seperti saiz zarah, ketumpatan pukal, ketumpatan zarah dan keliangan, pengekalan air, nilai pH, kekonduksian elektrik, kapasiti pertukaran kation dan boleh tukar, kation K, Ca, Mg, Na, kandungan nutrien dan nutrien. pengekalan. Kemudian, percubaan lapangan di bawah sistem fertigasi telah dijalankan menggunakan campuran media pertumbuhan untuk menyiasat kesannya terhadap prestasi pertumbuhan dan hasil *Capsicum annuum* L. Var. Kulai. Eksperimen ini dijalankan sebagai reka bentuk plot belah dua faktor dan sampel disusun dalam reka bentuk blok lengkap rawak (RCBD) dengan tiga blok. Analisis media seperti pH dan kekonduksian elektrik, jumlah karbon organik, nitrogen, dan sulfur, kapasiti boleh tukar kation dan kandungan nutrien kation boleh tukar, manakala ciri pertumbuhan tumbuhan, saiz akar, bahan kering, dan kandungan nutrien buah diukur dalam eksperimen ini. Keputusan menunjukkan bahawa T2 mempunyai potensi untuk menjadi agen pengapuran. Baja organik dan penambah kesuburan tanah kerana mengandungi pH tinggi (7.89), kekonduksian elektrik (2.70dS/m), kapasiti boleh tukar kation (12.57cmolc/kg), pengekalan nutrien dan jumlah kandungan nutrien N (0.58%), P (13.90mg/l), dan K(191.70mg/l). Walau bagaimanapun, T2 kekurangan pengudaraan dan pengekalan air kerana keliangan yang rendah (24.3%). Dapatan kajian kedua ialah T1 dalam kadar baja 100% mampu meningkatkan pertumbuhan dan pengeluaran *Capsicum annuum L. Var. Kulai* dalam tempoh 4 bulan dengan meningkatkan ketinggian tumbuhan (57.0cm), jumlah luas daun (3668.36 cm2), kandungan klorofil (64.0), bilangan (58) dan berat hasil (1008g) *Capsicum annuum L. Var. Kulai* dalam kadar baja standard kerana mencapai keadaan keseimbangan optimum dalam pH (5.58)) dan kapasiti boleh tukar kation (15.64 cmolc/kg) dalam media pertumbuhan. Dalam kajian ketiga, T2 menunjukkan hasil yang memberangsangkan kerana ia mampu menggalakkan pertumbuhan dan pengeluaran *Capsicum annuum L. Var. Kulai* dalam tempoh 4 bulan dengan memberikan hasil yang lebih baik dalam ketinggian tumbuhan (62.0cm), jumlah luas daun (3807.88cm2), kandungan klorofil (66.2), berat hasil (1115g) dalam mengurangkan 50% kadar baja. T2 juga meningkatkan penyerapan air dan nutrien dengan menggalakkan diameter akar (1.73mm), luas permukaan akar (267.60cm2), dan isipadu akar (10.66cm3) *Capsicum annuum* L. Var. Kulai. Selain itu, T5 dan T7 juga meningkatkan pertumbuhan tumbuhan dan pengeluaran *Capsicum annuum L. Var. Kulai* dalam 50% kadar baja kerana pengekalan air dan nutrien yang tinggi, keliangan, dan tahap kapasiti boleh tukar kation. Media pertumbuhan T2 dan T5 lebih menguntungkan dan menghasilkan kadar kos faedah yang tinggi kerana ia mampu meningkatkan pengeluaran tumbuhan, dan mengurangkan kos bahan mentah dan baja. Dapatan ini mengesyorkan petani menggunakan formulasi media pertumbuhan T2 dan T5 yang meningkatkan kecekapan penggunaan nutrien dengan menggalakkan prestasi tumbuhan *Capsicum annuum L. Var. Kulai*, dan kurangkan penggunaan baja.

Kata Kunci: Sisa Pertanian, Percubaan Lapangan, Analisis Media, Habuk Sabut Kelapa, Abu Tempurung Kelapa, Biochar Kulit Inti Sawit.

SDG: MATLAMAT 4: Pendidikan Berkualiti, MATLAMAT 12: Penggunaan dan Pengeluaran Bertanggungjawap, MATLAMAT 15: Kehidupan di Darat

ACKNOWLEDGEMENTS

Alhamdulillah

My deepest gratitude goes to the most merciful almighty, Allah for giving me opportunity, good health, perseverance, and strength to complete my master study. It is such a blessing and pleasure for me to work under supervision of Associate Professor Dr. Susilawati Kasim within 3 years of study period. Her continuously support and encouragement played a vital role for me to complete my study. I thank her a lot for giving me a great chance to learn new things throughout this time. I want to give appreciation to both of my parents and siblings for supporting me to finish my study.

I also want to thank my committee supervisor, Associate Professor Dr. Siti Zaharah Sakimin and Dr. Samsuri Abd. Wahid. I am also felt indebted to all staff and laboratory technician from Department of Soil Science Management, and Department of Crop Science, Faculty of Agriculture for helping me during my study. I would like to extend my gratitude to Siti Norliza Binti Mohd Din for always helping and be with me through thick and thin situation during my study period. I would also like to give appreciation to Natrah Atira binti Amran for always giving an encouragement during my study period. My heartiest thank also goes to UPM for chosen me as one of the Grant Research Fellowship (GRF) scholarship recipient and sponsored my cost of study throughout one years of my study period.

Next, I would like to extend my gratitude to KY Global Sdn. Bhd. for supplying me with palm kernel shell biochar and coconut ash. Next, I would like to thank

all of my friends who have patiently extended their help for me to complete my work. Last but not least, may Allah showered blessing and reward the good deed that all of you give with the highest treasure.

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Date: 13 January 2025

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrometer
ADP	Adenosine diphosphate
AFP	Air-filled Porosity
AFS	Air-Filled Surfaces
Al	Aluminum
ANOVA	Analysis of Variance
ATP	Adenosine triphosphate
B	Boron
CFU	Colony Forming Unit
CV	Coefficient of Variation
cv.	Cultivar
C	Carbon
Ca	Calcium
CCD	Coconut Coir Dust
Cd	Cadmium
C:N	Carbon to Nitrogen Ratio
CEC	Cation Exchange Capacity
CPO	Crude Palm Oil
Cr	Chromium
CRD	Completely Randomized Design
CSA	Coconut Shell Ash
CSC	Coconut Shell Charcoal
Cu	Copper

DAP	Day After Planting
DAT	Day After Transplanting
DNA	Deoxyribonucleic Acid
DOA	Department of Agriculture
DOS	Department of State
DVS	Department of Veterinary Services
EC	Electrical Conductivity
EFB	Empty Fruit Bunch
FAO	Food and Agriculture Organization
DVS	Department of Veterinary Services
EC	Electrical Conductivity
STAT	Statistical Database
FC	Field Capacity
Fe	Iron
FFB	Fresh Fruit Bunche
FTIR	Fourier Transform Infrared Spectroscopy
FW	Fresh Weight
GFN	Grain Fineness Number
gs	Stomatal Conductance
HHV	Higher Heating Value
HTC	Hydrothermal Carbonization
HTL	Hydrothermal Liquefaction
HTG	Hydrothermal Gasification
ICP-OES	Inductively coupled plasma optical emission spectroscopy
K	Potassium

MPOB	Malaysia Palm Oil Board
MF	Mesocarp fibre
Mg	Magnesium
Mn	Manganese
N	Nitrogen
Na	Sodium
NH_3	Ammonia
NH_4OAc	Ammonium Acetate
Ni	Nickel
NUE	Nitrogen Use Efficiency
OPT	Oil Palm Trunks
OPF	Oil Palm Frond
O_2	Oxygen
P	Phosphorus
Pb	Lead
PCE	Pyrometric Cone Equivalent
PDA	Plant Derived Ash
Ps	Photosynthesis
PGPR	Plant Growth Promoting Rhizobacteria
PKO	Palm Kernel Oil
PKSB	Palm Kernel Shell Biochar
POME	Palm Oil Mill Effluent
RAW	Readily Available Water
R:S	Root to shoot ratio

RCBD	Randomized Completely Block Design
RNA	Ribonucleic acid
S	Sulfur
SAS	Statistical Analysis System
SEM	Scanning Electron Microscope
Ti	Titanium
Ts	Transpiration
v/v	Volume per volume
WAT W	Week After Transplant Water
BC	Buffering Capacity
WUE	Water Use Efficiency
WS	Water Stress
XRF	X-ray fluorescence
Zn	Zinc

CHAPTER 1

INTRODUCTION

Malaysia produces a substantial amount of agricultural biomass waste which present a great opportunity for harnessing biomass energy in an eco-friendly and commercially-viable manner (Shuit et et al*.,* 2009). The major agricultural crops grown in Malaysia are rubber (39.67%), oil palm (34.56%), cocoa (6.75%), rice (12.68%) and coconut (6.34%). Only 27.0% is used out of the total quantity of residues generated either as fuel for the kiln drying of timber, for the manufacture of bricks, the curing of tobacco leaves, the drying rubber-sheets and for the manufacture of products such as particle board and fibre board. The rest has to be disposed of by burning (Zhang et al, 2015). Malaysia also the second largest oil palm producer after Indonesia in the world. As outlined in the research conducted by Greenfield et al. (2019), the soybean industry generated a considerable biomass volume, estimated at 70 million dry tons in 2017. Projections indicate a potential increase to 90 million dry tons by 2023, attributed mainly to yield improvement initiatives.

Oil palm industry generates about 70 million ton of biomass residue in Malaysia (Shuit et et al*.,* 2009). The palm plantation produces huge quantity of palm wastes such as oil palm frond (OPF), palm kernel shell (PKS), empty fruit bunch (EFB), palm trunk and mesocarp fibers (Mohammed., 2011). Palm kernel shells (PKS) are recovered during the extraction of crude palm oil (CPO). Then, the palm kernel shells are undergoing the pyrolysis process in production of biochar. Pyrolysis is a process for decomposing organic materials thermally under oxygen-free conditions in the temperature range between 300°C to 900°C. The parameters that influence the products of the pyrolysis processes include the reaction temperature, heating rate, and residence time. Mohammad et al. (2013), and Zhang et al. (2015) reported that the yields of biochar and acidic functional groups decreased with increasing pyrolysis temperature, whereas those of the basic functional groups, ash content, pH, and carbon stability increased.

Coconut (*Cocos nucifera*) is an important member of the *Aceraceae family* (palm family). It can grow up to 30m tall, with 4 to 6m long pinnate leaves and 60 to 90cm pinnate. In year 2012, Malaysia is generated more than 25000 metric tons of biomass waste (Abdullah and Sulaiman, 2013). Coconut industry produced different parts of wastes namely coconut head, shell, husk, kernel and meat (inner part). In the past, agro- waste have been utilized as animal feed, organic fertilizer, soil amendments or decay naturally in fields, discarded or burnt (Agamuthu, 2009). Coconut shell ash generally contains large percentage of K_2O, SiO_2 and CaO (Oluremi, 2012) and high in phosphorus. Coconut shell is an coconut coir dust and is available in very large quantities throughout the tropical countries of the world. Coconut shell ash (CSA) was produced by carbonization process burning the coconut shell in the absence of air (Oluwole et al., 2017). Besides, the use of CSA able to improve the pH, cation exchange capacity (CEC), water-holding capacity and microbial activities of the soil. Coconut coir dust is also known as the cocopeat that is commonly used in soilless culture for horticultural crops, such as tomato, chili and rock melon. It is made from the coconut husk and coir fiber, and the end product consists of spongy fibers and dust. CCD is free from phytopathogens, easy to handle and transport, approximately 25% air-filled porosity (AFP) and 34% readily available water (RAW) with adequate water buffering capacity (WBC).

1.1 Problem Statement

The higher the production of agriculture product, the higher the production of agriculture waste. The main problem of agricultural activities is the improper agricultural waste management system. Poor agriculture waste management are detected in contribution major sources of environmental issues. (Peter, 2010). Moreover, less study towards the agriculture waste management and most of the study only concentrated on housing, commercial, industrial and poultry (Sharma *et.al*, 2018). These wastes can compose of organic matter which has high potential to be converted into value added products such as growing media (Samuelson et al., 2009).

The growing media play a critical role in the propagation of vegetable seedling and support plants by providing water, air and nutrients (Abad et al., 2002; Bilderback et al., 2005; Yilmaz et al., 2014; Olaria et al., 2016; Oagile et al., 2016). However, different growing media vary greatly in composition, particle size, pH, aeration and ability to hold water and nutrients (Oagile et al., 2016). A potential low cost and environmentally friendly supercapacitor has been prepared from Palm Kernel Shell Biochar (PKSB) which is known with the characterizations that the raw palm kernel biochar need further treatment to become supercapacitor electrodes to replace activated carbon.

Besides that, one of the soilless materials widely available in the tropics is the coconut coir dust or commercially known as cocopeat. However, cocopeat is neutral to slightly acidic. The ideal pH range for coco peat is between five and six, but it can be challenging to maintain this range. Moreover, cocopeat high in potassium and sodium that can harm the plant. Cocopeat also more expensive and high cost compared to other growing mediums such as coconut shell ash or palm kernel shell ash, depending on the quality (Oagile et al., 2016). It has been recognized to have high water holding capacity which causes poor air-water relationship, leading to low aeration within the medium, thus affecting the oxygen diffusion to the roots. Therefore, growing substrates consist of either a single component or mixtures can help in support plants by providing water, air and sufficient nutrient, hold water and provide good aeration to the plant root system that enhance plant uniform emergence, growth and development (Biondo and Noland, 2000).

Chilli pepper (*Capsicum annuum* L) is one of the challenging crops by farmer and high fertilizer consumption need in chilli growth and production. So, the farmers choose to use high doses fertilizer to meet the nutrient requirements. Each planting seasons, farmers use K fertilizer as much as 150 to 180 kg ha^{-1} K_2O or KCl 250 to 300 kg ha^{-1} (Nurlenawati et al., 2010). According to Hafif and Wardani (2005) state that the continuously application of chemical fertilizers in high doses and frequently will causing the decrease in productivity, land resources quality and environmental pollution. Hafif and Wardani (2005) also reveals that nutrients excess that not utilized by plants can turn into pollutants and lead to nutrient imbalances and in turn declining plants response.

1.2 Research Objectives

a. To determine the physio-chemical properties of different mixtures of agricultural waste materials.

b. To investigate the effect of different mixtures of agricultural waste materials on the growth performance of *Capsicum annuum* under fertigation system technique.

c. To identify the beneficial use of mixtures of agricultural waste materials in minimizing fertilizer consumption in *Capsicum annuum* production in fertigation system.

d. To evaluate the cost-benefit of different mixtures of agricultural waste materials under fertigation system.

1.3 Conceptual Framework

The low fertility of acidic soils is manifested through the exploration of increase nutrient uptake and growth performance of the chilli. The addition of agricultural wastes and also fertigation system is expected to increase nutrient uptake efficiency and also the growth performance and production of chilli . The Figure 1.1 shows the steps to be taken to improve soil productivity and the outcomes expected.

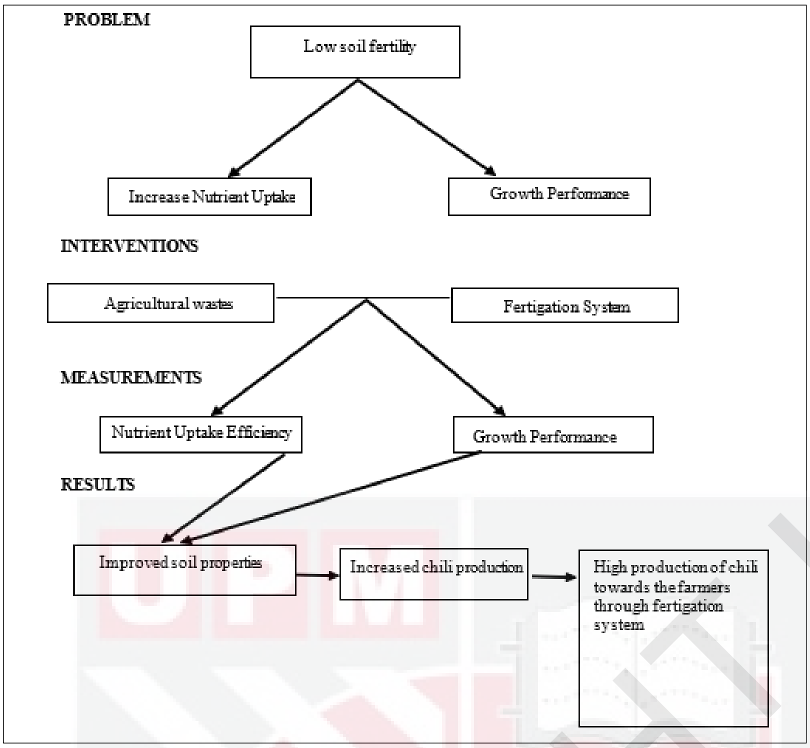


Figure 1.1 : Conceptual Framework

CHAPTER 2

LITERATURE REVIEW

2.1 Agricultural Wastes

2.1.1 Oil Palm Plantation

Malaysia is the second largest oil palm producer after Indonesia in the world. In 2009 Malaysia produced around 17,656,000 tons of palm oil with total area of is 4691,160 ha. (Shafie et al*.,* 2012). The palm oil sector generates the largest amount of biomass, estimatedat 80 million dry tons in 2010. This is expected to increase to about 100 million dry tons by 2020, primarily driven by increases in yield (National Biomass Strategy 2020). According to the Malaysia Palm Oil Board (MPOB), approximately 10% of the useable products have been produced from oil palm tree while 90% are waste products (Malaysia Palm Oil Board, 2011).

The palm plantation produces huge quantity of palm wastes such as oil palm frond (OPF), palm kernel shell (PKS), empty fruit bunch (EFB), palm trunk and mesocarp fibers (Mohammed et al.,2011). In the plantations, oil palm fronds (OPF) are available throughout the year as they are regularly cut during harvesting of fresh fruit bunches (FFBs) and pruning of the palm trees. Additional fronds as well as oil palm trunks (OPT) become available in the plantations during the replanting of oil palm trees every 25 to 30 years. In the mills, empty fruit bunches (EFBs) remain after the removal of the palm fruits from the fruit bunches. Mesocarp fibre (MF) and palm kernel shells (PKS) are recovered during the extraction of crude palm oil (CPO) and palm kernel oil

(PKO), respectively. In addition, palm oil mill effluent (POME) accumulates as a liquid biomass at the mills (Shafie et al*.,* 2012).

Kyairul (2007) and Chan (2011) demonstrated that the biomass generated from the oil palm sector is estimated by multiplying the residue ration of EFBs (21.14%), PKS (5.67%), MF (12.72%) and POME (67%) with yearly oil palm FFBs production (Figure 2.2). In this estimation only are considered. The estimation excluded OPF and OPT and this is because the vast majority of the oil palm biomass (especially OPF and OPT) being generated today is returned to the field to release its nutrients and replenish the soil. The biomass returned to the field as organic fertilizer plays an important role to ensure the sustainability of FFBs yields (Shafie et al., 2012).

According to MPOB, 12 tonnes of dry OPF is generated per hectare, 75% of oil palm planted areas were removed for pruning and only 50% were removed from the plantation. These wastes can potentially be transformed into soil amendment by using appropriate techniques. These wastes were used widely to improve soil fertility and plant growth. Palm kernel shells (PKS) biochar able to increase the availability of magnesium and potassium in the soil (Sohi et al*.,*2009).

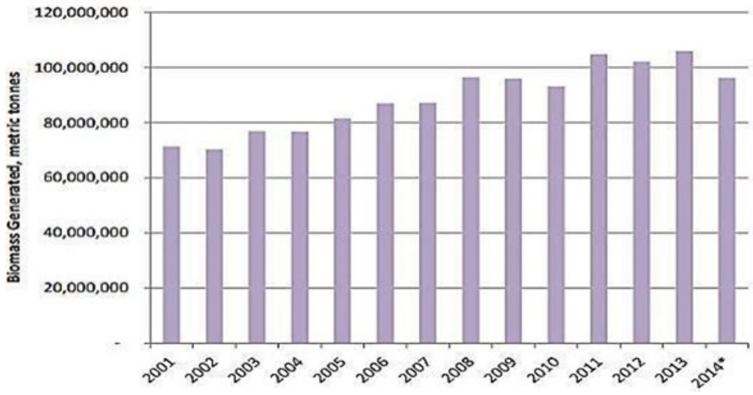


Figure 2.1 : Oil palm residue generated between years 2001-2014
(Source: MPOB, 2014; Pariatamby, 2017)

2.1.2 Coconut Plantation

Coconut is a well-known fruit in Malaysia and the degree of diversification of coconut utilization for food products is a remarkable achievement. Coconut (*Cocos nucifera*) is an important member of the *Arecaceae* family (palm family). It can grow up to 30 m tall, with 4 to 6 m long pinnate leaves and 60 to 90 cm pinnate. Coconut is a well-known fruit in Malaysia and the degree of diversification of coconut utilization for food products is a remarkable achievement. Abdullah (2013) reported that Malaysia is generated more than 25000 metric tons of biomass waste in year 2012. Coconut waste is a copious agricultural waste and it also composes part of kitchen waste. The waste is generated from different parts of the coconut head, namely the husk, kernel and meat (inner part). Coconut shell is one of the disposals wastes that came from agricultural activities. Bamgboye and Jekayinfa (2006) regretted that 90% of coconut (empty fruit bunches, fibers, fronds, trunks, shell) was discarded as waste and either burned in the open air or left to settle in waste ponds. Based on economic as well as environmental related issues, efforts should be directed worldwide towards coconut management issues (utilization, storage and disposal).

The used of coconut shell as one of the composite materials in the production of concrete driven by the problem caused by the disposal of solid waste. Coconut shell represents more than 60% of the domestic waste volume and had a serious disposal problem for local environment (Gunasekaran et al., 2012). However, these wastes can be used as potential material or replacement material in construction industry. Besides that, coconut shell are potential candidates for the development of new composite material in concrete mix design because of their high strength and modulus properties (Kambli et al., 2014). Coconut is grown in more than 90 countries in an area of 14.231 million hectare with a total production in terms of copra equivalent of 11.04 million tonnes (MT). Indonesia (25.63%), the Philippines (23.91%), and India (19.20%) are among major coconut-producing countries in the world (Verma et al.,2015).

Apart from that, the usage of coconut shell in concrete are much cheaper as it is an agricultural waste that was dumped and not been use. A better and a green environment can be created by using this coconut shell (Gunasekaran et al., 2013). In the past, such types of agro-waste have been utilized as animal feed, organic fertilizer, soil amendments or are otherwise allowed to decay naturally in fields, discarded or burnt, whereas current practices are on-farm burning, burial, stockpiling and landfilling (Agamuthu, 2009). Despite its reuse as animal feed/ supplement, it also can be utilised as organic fertilizer via bioconversion. As example, the use of coconut ash (CA) able to improve the pH, cation exchange capacity (CEC), water-holding capacity and microbial activities of the soil. Coconut ash generally contains large percentage of K_2O, SiO_2 and CaO (Oluremi, 2012) and high in phosphorus. Coconut is the third most important industrial crop in terms of the total planted area in Malaysia. In 2009, local coconut oil production was reported to be around 455,000 tonnes (Shafie et al*.,* 2012). Koopmans and Koppejan (1997) reported that the biomass generated ratio from the coconut sector is coconut husk (33%) and shell (12%). The results of the studied parameters after the thermogravimetric experiment for the proximate test are obtained. The results were found to be 5.56% moisture content, 70.82% volatile matter, 21.8% fixed carbon and ash content of 1.8% respectively. This result trend is nearly similar to those obtained on palm kernel shell (Figure 2.1).

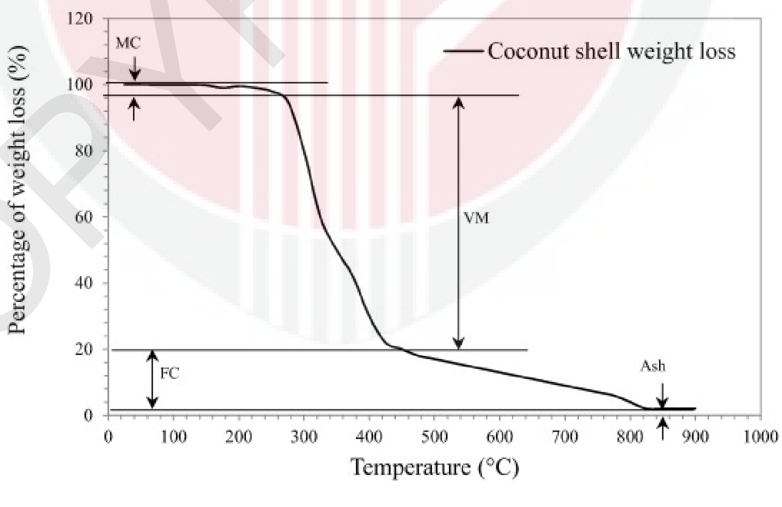


Figure 2.2 : Thermogravimetric coconut shell weight loss against temperature
(Source: Ahmad et al., 2022)

2.2 Coconut Ash

2.2.1 General Overview

Coconut is belonging to palm family and one of the industrial crops in Malaysia, which is the third biggest in plantation area size. Basically, coconut is a source of edible oil and coconut milk, which is the main ingredient of most of Malaysian foods. In 2009, the total domestic coconut production in Malaysia was about 459,000 tons. From coconut processing, coconut husk (0.166 million tonnes), coconut shell (0.735 million tonnes), coconut frond (0.103 million tonnes) and coconut empty bunches (0.022 million tonnes) are obtained as a by-product (Inayat et al., 2017). These potential biomasses can be utilized for heat and power generation via different thermochemical process or convert into liming substance and fertilizer to enhance the fertility of soil (Inayat et al., 2018). Coconut ash is residue created from burning the shell or husk of a coconut. Coconut shells were sun dried to ease the removal of the coconut fiber. The shells were ripped out and washed from any unwanted substances. Coconut shells were subjected under heating process at 400˚C to 450˚C for five minute using furnace to change its properties to charcoal. Charcoal coconut shell was then left to cool down in room temperature before being crushed manually. Small sizes of crushed charcoal coconut shells were then grinded using LAAV with 1200 cycles until became ash in physically. The charcoal was divided into two and one part was kept as charcoal while the other part was subjected to carbonization. Thus, coconut ash can be called as waste product from Coconut shell charcoal (CSC). CSC was produced by burning the coconut shell in the presence of air while CSA was produced by burning the coconut shell in the absence of air called as carbonization process (Oluwole et al., 2017). The carbonization process converts coconut shells to charcoal by heating in the absence of oxygen.

2.3 Production of Coconut Ash

2.3.1 Carbonization

The coconut shell was grinded to form coconut shell powder, the powder was packed in a graphite crucible and fired in electric resistance furnace at temperature of 1300ºC to form coconut shell ash (Figure 2.5) contains about 65% to 75% volatile matter and moisture which are removed largely during the carbonization process (Madakson et al., 2012). The carbonization process converts coconut shells to charcoal by heating in the absence of oxygen. The collected char and the charcoal were grinded into powders with the aid of laboratory ball mill followed by sieving with sieve shaker to obtain 150 µm. The production process products are as shown in Figure 2.6. Carbonization is the production of charred carbon from a source material. The process is generally accomplished by heating the source material usually in the absence or limited amount of air to a temperature sufficiently high to dry and volatilize the substance. Therefore, CSC was produced by burning the coconut shell in the presence of air while CSA was produced by burning the coconut shell in the absence of air (Oluwole et al., 2017). Prior to use, coconut shells were crushed and sieved to obtain particles with sizes less than 2 mm. Subsequently, coconut shells were loaded on a ceramics boat which was placed inside a stainless- steel tubular reactor with 38 mm internal diameter. The coconut shells were heated up to a carbonization temperature (400°C, 600°C, 800°C, and 1000°C) at a heating rate of 10°C/min and were held for at least 2h at the carbonization temperatures under N_2 gas flow. After carbonization the samples were cooled to room temperature under N_2 flow. The carbonized samples were crushed and sieved to obtain particles with sizes less than 3.35 to 4.75 mm. The schematic diagram of apparatus for the preparation of activated carbon by physical activation was shown in Figure 2.4.

Figure 2.3 : Pyrolysis unit
(Source: Babel and Jurewicz, 2004)

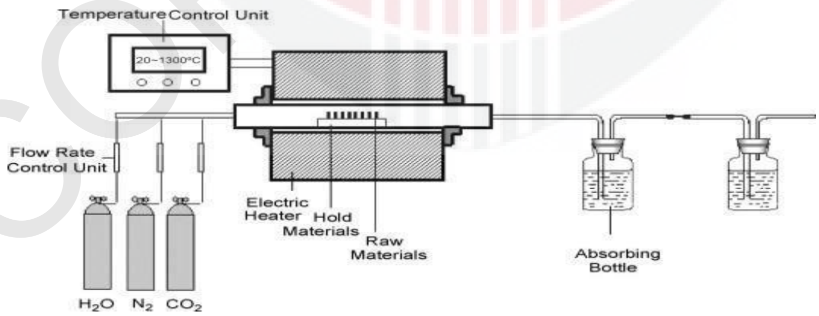


Figure 2.4 : The diagram of apparatus for the preparation of activated carbons using physical activation
(Source: Li et al.,2008)

Figure 2.5 : Photograph of coconut shell ash
(Source: Madakson et al., 2012)

Figure 2.6 : Production process products: coconut shell – coconut shell particulate
(Source: Oluwole et al.,2017)

There are two types of activation processes to produce activated carbon from carbonaceous materials which is chemical and physical activation processes. Physical activation procedure involves a two-step process such as carbonisation, followed by activation using steam, oxygen or carbon dioxide as an activating agent (Yuen and Hameed, 2009). However, in the chemical activation procedure, carbonisation and activation processes occur in a single stage using chemicals as an activating agent such as potassium hydroxide (KOH), phosphoric acid and zinc chloride (Ncibi et al*.,* 2009). The production of activated carbon from coconut shell using microwave was done by Li et al*.* (2009) and Yang et al*.* (2010). The activated carbon obtained from the study had high specific surface area with pore structure falling in the range of micropores, rendering it unsuitable as super capacitor electrode. Super capacitor is attracting attention nowadays owing to its capability in storing more energy, high power discharge ability and longer life cycle compared with other available energy storage devices (Yuan et al., 2005). Super capacitor electrode is one of the activated carbons used in electronic industry. Super capacitor can provide high power capability (60s to 120s), excellent reversibility (90% to 95% or higher) and long-life cycle (more than 105) (Zhang et al., 2009). In a super capacitor, the activated carbon used must have porous texture which is the main criterion of a double electric layer with high capacity and charge exchange.

The pore structure of the activated carbon used is important for optimal performance of carbon materials as an electrode for super capacitor (Babel and Jurewicz, 2004). The biochar production was carried out in a slow pyrolysis unit as illustrated in Figure 2.3, where it is a double walled cylindrical chamber with two hollow portions covered with charcoal of shells in the smaller part and dried coconut shells of about 20 kg in the bigger part. Above all, there exist a narrow chimney along with the lid which helps in removing the exhaust and preventing the formation of ash due to excess heat inside. This setup constitutes a pyrolytic chamber wherein a huge biomass quantity can be converted to biochar under high temperature. The dried shells were then exposed to 450°C in the chamber resulting in carbonized shells called biochar with a high amount of fixed carbon. The pyrolysis was carried out continuously for 2 hours without any disturbance and removal of chimney. After completion of the process, when the unit was cooled to its normal temperature, the chimney was removed and the lustrous and good conditioned shells of about

6 kg were removed from it. There was 30 % yield recovery from 20 kg of coconut shells. The adsorbent carbon was broken into small pieces, crushed using a wooden hammer, sieved to obtain a size less than 2 mm and stored in hot air oven at 60°C for studying its characteristics. For adsorbent carbon to have desired properties, the temperature should be maintained where carbonization takes place. The carbonization influences the molecular architecture of carbonized material. Disturbances in the elementary microcrystalline structure by the presence of imperfect or partially burnt off carbon layers changes the arrangement of electron cloud in the carbon skeleton. As a result, unpaired electrons appear and the condition influences the adsorption properties of the activated carbon, especially for polar and polarisable substances (Ekpete et al., 2011). The temperature of 450°C was chosen for the production of carbonized shells. It was observed that if the temperature increases, there is increase in ash content and huge loss of carbon was notice

2.4 Physical Properties of Coconut Ash

2.4.1 Particles Size Analysis

Numerous studies have explored the multifaceted applications of coconut ash across diverse fields. For instance, researchers have investigated its potential as a sustainable construction material, examining its impact on the mechanical properties of concrete and evaluating its efficacy in enhancing both the durability and environmental sustainability of construction projects (Rajan et al., 2007). In agriculture, studies have delved into the effects of coconut ash as a soil amendment, focusing on its influence on soil fertility, nutrient retention, and crop yield, providing insights into its role in promoting sustainable agricultural practices (Aigbodion et al., 2010).Moreover, coconut ash has garnered attention as a precursor for activated carbon, with investigations into its activation process and the resultant material's effectiveness in water purification and air quality improvement, showcasing the versatility and environmental benefits of utilizing coconut ash in advanced materials. These studies collectively highlight the diverse and promising avenues for the application of coconut ash, ranging from construction to agriculture and materials science (Rajan et al., 2007).

2.4.2 Density Measurement

Density measurement studies on coconut ash have been integral to understanding its physical characteristics and potential applications. Researchers have conducted comprehensive investigations, employing techniques such as helium pycnometry or displacement methods to determine the bulk and skeletal densities of coconut ash particles. These studies have unveiled valuable insights into the porosity and compactness of the material, crucial factors for applications ranging from construction materials to adsorption processes. By establishing the density profile of coconut ash, researchers can better comprehend its structural composition, aiding in the optimization of its usage in various fields, including environmental remediation, where porosity and surface area play pivotal roles in adsorption capacity. These density-focused studies contribute to a foundational understanding of coconut ash properties, offering a basis for informed decision-making in its application across diverse scientific and industrial domains (Bienia et al., 2003; Aigbodion et al., 2010)

2.4.3 Water Absorption Ability

Coconut shell (CS) has high water absorption ability because of its open structure containing many hydroxyl and acetyl group, hence hemicelluloses can partly soluble in water and hygroscopic (Frederick et al., 2004). The chemical treatment can optimize the interface of CS to reduce its hydrophilic as the excessive content of water will weaken the structure of CS (Bhaskar and Singh, 2013). The most usual treatment for CS is by using Sodium Hydroxide (NaOH) as it can reduce the hydroxide (OH) compound in CS, hence reduce absorption ability (Munirah and Ahmad, 2012; Thaker et al., 2013). Besides that, some researchers have burnt CS into charcoal form and used as a filler to resist resistance to freezing, crushing and absorption (Dung, 2014).

$$CS\text{-}OH + NaOH \Rightarrow CS\text{-}O\text{-}Na^{+} + H_2O$$

2.4.4 Refractoriness

The Pyrometric Cone Equivalent (PCE) as recommended by ASTM Test C-24 was used in the determination of the refractoriness of the sample (Aigbodion et al., 2010). The coconut shell ash was observed to have Seger Cone No. 22, with equivalent temperature of 1500^{o}C. This means coconut shell ash can withstand operating temperature of 1500^{o}C without load (Bienia et al., 2003; Aigbodion et al., 2010; Siva et al., 2011; Arun et al., 2011).

2.4.5 Micro Structural Analysis

The microstructure and the chemical compositions of the phases present in the coconut shell ash was studied using a JOEL JSM 5900LV Scanning Electron Microscope equipped with an Oxford INCATM Energy Dispersive Spectroscopy system. The sample was placed on sample holder and the images were captured under various magnifications as shown in Figure 2.7. Prior to it, sample was applied with the gold coating to avoid charge effect and to obtain clear images. The SEM was operated at an accelerating voltage of 5 to 20 kV (Aigbodion et al., 2010).

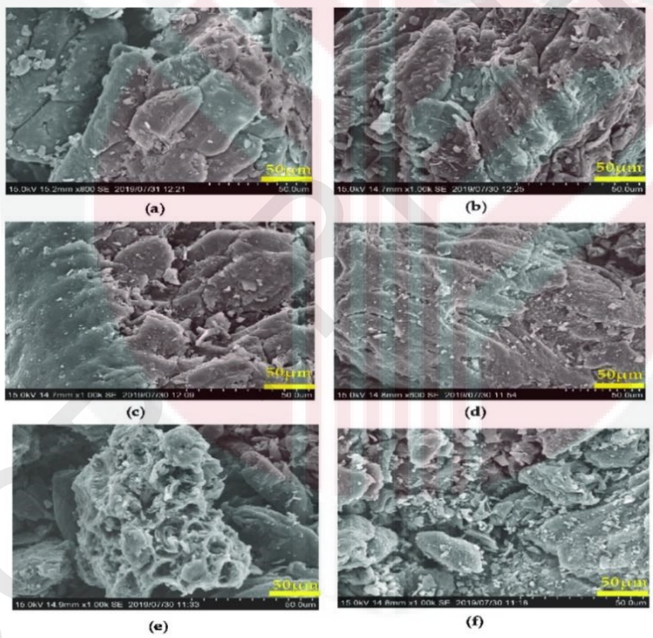


Figure 2.7 : SEM results from coconut shells: (a) coconut shell and bio-char, (b) 400 °C, (c) 500 °C, (d) 600 °C, (e) 700 °C, and (f) 800 °C.
(Source: Sarkar et al.,2020)

2.4.6 Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR-8400S Fourier transform infrared spectrophotometer was employed for the detailed analysis of functional groups within coconut shell ash. This spectrometer, equipped with a sensitive detector capable of measuring functional groups down to a predetermined minimum detectable level, utilized a personal computer with compatible software for real-time updates of the spectral profile during sample collection. The FTIR system operated at a resolution of 1cm^-1, a 22.0-meter path length, and featured a broad-band MCT detector. Data analysis was conducted using reference spectra, and concentrations were verified using CTS spectra (Rajan et al., 2007). The FTIR analysis identified twenty main peaks in the coconut shell ash, as illustrated in Figure 2.8 and detailed in Table 2.1. These peaks provided valuable information about the composition, with quartz contributing to bands at 1132cm^-1 and 443.64cm^-1, mullite manifesting at 3797cm^-1, and carbon groups exhibiting series of bands between 4091.15cm^-1 and 4617.74cm^-1. Additionally, overlapping signals in the range of 1220cm^-1 to 1434.12cm^-1 indicated the presence of quartz, mullite, and the vitreous phase in the original ash (Rajan et al., 2007).

Thus, the confirmation of the presence of Quartz, Mullite, carbon, and vitreous phases in the coconut shell ash aligns with previous studies conducted by Ejilofor et al. (1997) and Arun et al. (2011). The FTIR analysis revealed distinct peaks corresponding to these constituents, providing a comprehensive understanding of the ash's composition. This confirmation is crucial for applications in diverse fields, such as construction materials or environmental remediation, where knowledge of specific phases can inform the material's behavior and suitability for various purposes. The consistency of these findings with prior research enhances the reliability and relevance of the identified components in coconut shell ash (Ejilofor et al., 1997; Arun et al., 2011)

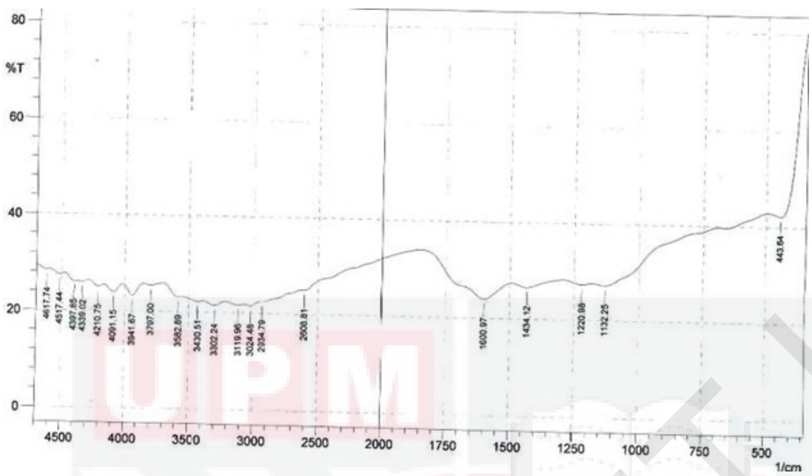


Figure 2.8 : FTIR spectrum of Coconut shell ash
(Source: Madakson et al., 2012)

Table 2.1 : Identification Peaks of the FTIR analysis

No.	Peak	Intensity	Correlation Intensity	Base (H)	Base (L)	Area	Correlation Area
1	443.64	42.22	13.14	494.76	339.48	45.91	10.16
2	1132.25	27.19	1.56	1179.51	692.47	231.18	2.80
3	1220.98	27.35	0.48	1296.21	1180.47	64.53	0.44
4	1434.12	26.52	1.11	1492.95	1297.17	110.30	1.53
5	1600.97	23.95	5.35	1848.83	1493.92	198.11	14.83
6	2608.81	24.93	0.27	2630.03	1849.8	414.86	0.27
7	2934.79	22.37	0.082	2944.44	2630.99	196.74	0.52
8	3024.48	21.48	0.53	3070.78	2945.40	82.81	0.58
9	3119.96	21.53	0.45	3218.34	3071.74	96.85	0.65
10	3302.24	21.40	0.94	3390.01	3219.30	112.69	1.60
11	3430.51	22.18	0.35	3553.96	3390.97	105.29	0.45
12	3582.89	23.07	0.57	3703.45	3554.93	91.50	0.81
13	3797.00	25.37	0.37	3854.87	3704.41	89.13	0.50
14	3941.67	23.17	2.41	4016.89	3855.83	98.59	3.24
15	4091.15	23.86	1.55	4165.42	4017.86	89.77	1.98
16	4210.75	25.00	0.68	4287.90	4166.38	72.23	0.73
17	4339.02	25.85	0.33	4381.45	4288.86	54.13	0.26
18	4397.85	26.04	0.29	4476.93	4382.42	54.26	0.32
19	4517.44	27.36	0.58	4588.81	4477.89	61.74	0.48
20	4617.74	28.31	0.31	4700.68	4589.77	60.18	0.30

(Source: Madakson et al., 2012)

2.5 Chemical Properties of Coconut Ash

2.5.1 Mineralogical Characterization of the Coconut Shell *A*sh

The elemental analysis of coconut shell ash was conducted using the Mini Pal compact energy dispersive X-ray spectrometer (XRF), controlled by a PC running dedicated Mini Pal analytical software (Aigbodion, 2010). This system provides insights into the elemental composition of the ash. Additionally, X-ray diffraction (XRD) analysis was performed using a Philips X-ray diffractometer, with Cu Kα radiation and a scan speed of 30/min. The samples were rotated at precisely one-half of the angular speed of the receiving slit, maintaining a constant angle between the incident and reflected beams. The diffractograms, as reported by Madakson et al. (2012), displayed major peaks at 20.75°, 10.22°, and 35.40°, corresponding to inter-planar distances of 3.87Å, 8.66Å, and 2.54Å, respectively. The relative intensity of X-ray scattering at these peaks indicated the presence of Quartz (SiO2), Cordierite, syn (Mg2Al4Si5O18), and Moissanite (SiC) phases. Each phase was assigned a score of 44, 32, and 16, respectively, as detailed in Table 2.2 (Madakson et al., 2012). These findings contribute valuable information about the crystalline phases present in coconut shell ash, aiding in the understanding of its material properties and potential applications.

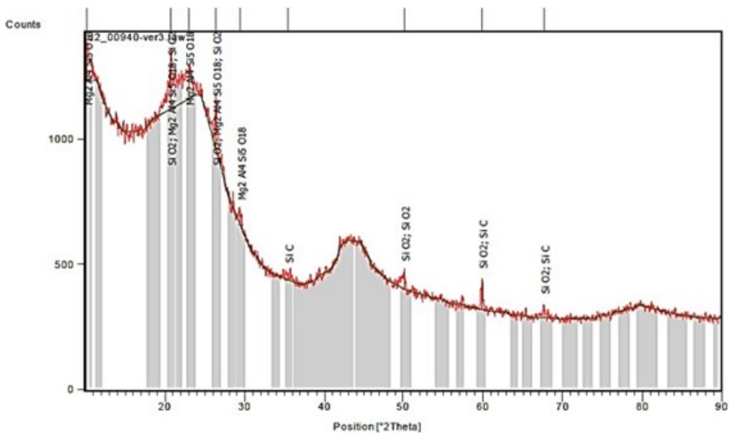


Figure 2.9 : XRD pattern of Coconut shell ash
(Source: Madakson et al., 2012)

Table 2.2 : Phases score at each peak

Visible Ref	Code Score	Compound	Name	Displacement [°2Th.]	Scale Factor	Chemic al Formula
*	00-043-0596	44	Silicon Oxide	0.000	0.912	SiO_2
*	00-013-0294	32	Cordierite, syn	0.000	0.590	$Mg_2 Al_4 Si_5 O_{18}$
*	01-089-1961	26	Quartz low, dauphinee-twinned	0.000	0.642	SiO_2
*	01-075-1541	16	Moissanite 6\ITH\RG	0.000	0.207	SiC

(Source: Madakson et al., 2012)

The results showed that SiO_2 has the highest percentage of all the compound and element present as revealed by the XRD analysis. Complete Mineralogical analysis carried out by X-ray diffraction also revealed that the ash contains each of these elements C, O, Mg, Al, Si" Fe, Na, K, Zn and none of these elements H, He, Li, Be, B, N, F, Ne, P, S, Cl, Ga, Ge, As, Se, Br, Kr, Rb, Sr, Y, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, I, Xe, Cs, Ba, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, which means that with the absence of all these other elements the coconut shell ash may not contain radioactive materials. The XRD result showed that both SiO_2 and SiC have a fine structure. This could be associated with pore size (Aigbodion et al., 2010). The XRF chemical composition of the coconut shell ash is represented in Table 2.3. XRF analysis confirmed that SiO_2, Al_2O_3, MgO and Fe_2O_3 were found to be major constituents of the ash. Silicon dioxide, iron oxide and alumina are known to be among the hardest substances. Some other oxides viz. CaO, K_2O, Na_2O and MnO were also found to be present in traces. The coconut shell ash can be used as particulate reinforcement in various metal matrixes due to presence of hard elements like SiO_2, Al_2O_3 and Fe_2O_3. This result of XRF is in agreement with the result of XRD obtained. Therefore, the present work suggests the possibility of using coconut shell ash as particulate in metal matrix composites since the chemical composition has close similarity with the XRF analysis of rick husk ash, bagasse ash and fly ash currently used in metal matrix composites (Bienia et al., 2003; Aigbodion et al., 2010; Siva et al., 2011; Arun et al., 2011).

Table 2.3 : XRF analysis of Coconut shell ash

Element	Percentage (%)
Al_2O_3	15.6
CaO	0.57
Fe_2O_3	12.4
K_2O	0.52
MgO	16.2
Na_2O	0.45
SiO_2	45.05
MnO	0.22
ZnO	0.3

(Source: Madakson et al., 2012)

Coconut ash contains large percentage K_2O, SiO_2 and CaO (Oluremi et al., 2012). The application of CA beneficial in soil stabilization applications such as soil liming, soil drying, and soil amendment (Sear, 2005). Chemical analysis of the coconut ash shows that it contains 62.43%, 17.9% and 8.79% of K_2O, SiO_2 and CaO respectively (Oluremi et al., 2012). The liquid limit ranges of coconut ash are between 58.9% and 67.2%, plastic limit ranges between 25% and 47.14%, and plasticity index is between 20% and 37%. The maximum dry density ranges of coconut ash are between 1.512 g/cm^3 and 1.62 g/cm^3 and the optimum water contents of coconut ash in range between 13.5% and 24%. Many research articles reveal that coal combustion by-products also have properties that are beneficial in soil stabilization applications such as soil drying, and soil amendment to enhance subgrade support capacities for pavements and floor slabs, reduction of shrink–swell properties of soils, and as stabilizer in aggregate road base construction and asphalt recycling. Three tests carried out by Oluremi et al. (2012) for each compound show the same result. Oluremi et al. (2012) also reveals that the coconut husk ash contains high percentage of K_2O (62.43%), SiO_2 (17.9%) which corroborate the fact that coconut husk ash is a pozzolanic material. Incineration of coconut husks produces ash containing 25% to 35% potash (Grimwood, 1975), and it has been demonstrated experimentally that the ash is in excellent fertilizer for young coconuts (Bonneau et al*.,* 2010).

2.5.2 Stabilize the pH, High in CEC and Enhance Microbial Activities

The soil pH increased with increased application rate of amendments with coconut husk ash at 10 t/ha having the higher pH of 6.40 than coconut husk unashed. The organic carbon increased significantly in both ashed and unashed coconut husk and corn cob when compared with the control (Ayeni, 2008; Njoku and Mbah, 2012). Phosphorus was found to be relatively higher in ashed coconut husk when compared with the unashed version. There was noticeable that fluctuation in available P pool in the various treatment incubated pots were lower than control when reach the twelve weeks incubation. Six weeks incubation of 10t/ha of ashed coconut gave the highest cation exchangeable capacity (CEC) over twelve weeks incubated pots of similar treatment (Awotoye et al*.,* 2014). This process also attributed to the microbial activities that can enhanced quicker mineralization. Molindo (2008) state that the activities of micro-organisms and other agents will encourage decomposition process and enhanced quicker mineralization.

2.6 Benefit Use of Coconut Ash toward Growth Media and Plant

Giovannini et al. (1993) reported that the addition of ash in one form or another to soil has been done for years through burning of agricultural residues but only in recent years has research begin to focus on the effects of application of ash on agricultural soils. Mbah et al. (2010) reported improved soil properties and increased maize grain yield when they tested the response of maize (*Zea may*) to different rates of ash application in acid ultisol in southeast Nigeria. Oditte et al. (2005) and Ojeniyi et al. (2007) reported increased crop yield when ash was used as soil amendment. Similarly, research result by Odedina et al. (2003), Adetunji (1997) and Owolabi et al. (2003) showed reduced acidity and increased nutrient availability in soil of southwest Nigeria amended with different types of ash relative to the control. Mbah et al. (2013) reported that ash application to soil increased maize growth and yield. The result also showed that ash application as soil amendment does not constitute agronomic and environmental problems since observed values of heavy metals, SAR, EPP and ESP are within tolerance limits.

Bonneau et al. (2010) indicated that coconut husk ash performed well when compared to a standard fertilizer primarily consisting of KCl, in a proportion of 2 to 2.5 kg of coconut husk ash for 1 kg of KCl. The same trend was found for vegetative growth (Table 2.4), flowering and yields (Table 2.5). The coconut palms without fertilization fell behind considerably and although the palms fertilized with aquatic plants grew and yielded a little better than the unfertilized control palms.

Table 2.4 : Vegetative growth of coconut palms

Variable	Treatment				
	Age of palms (months)	**No fertilizer**	**Coconut ash**	**Aquatic plant**	**Standard mineral fertilizer**
Collar girth (m)	36	1.10	1.55	1.25	1.48
	60	1.27	1.58	1.31	1.58
Number of green fronds per palm	36	14.8	23.6	17.1	22.5
	60	22.1	30.3	23.5	29.3
Length of frond (m)	36	3.40	4.42	3.93	4.37
	60	4.65	5.47	5.07	5.50
Leaf area index	36	0.49	1.55	0.78	1.40
	60	1.50	2.77	1.82	2.68

(Source: Bonneau et al., 2010)

Another example is given by the cumulative yield in the first two harvesting years (Table 2.5), which more than trebled between the control palms without fertilization and the palms fertilized with KCl or ash. Meanwhile the palms fertilized with aquatic plants produced slightly more than the unfertilized control palms but remained well behind the best two treatments. When correlating the growth and yields of the coconut palms with their nutritional status revealed by a leaf analysis, and found that it was a K deficiency that had caused the coconut palms without fertilization, or those fertilized with aquatic plants to fall behind. Coconut ash provides as much K and Cl as KCl, with non-limiting contents for the other nutrients and also SiO_2, a nutrient that proves to be inert since the difference in SiO_2 content between the husk ash and KCl treatments was not reflected in growth or yields.

Table 2.5 : Production of nuts from palms treated with coconut ash, aquatic plants and mineral fertilizer

Planting	Treatment			
Year	No fertilizer	Coconut ash	Aquatic plant	Standard Mineral fertilizer
5	3.9	36.9	8.1	26.7
6	21.8	67.7	31.4	66.3
Total	25.7	104.6	39.5	93.0

(Source: Bonneau et al., 2010)

2.7 Soil Fertility Improvement Method by Coconut Ash

2.7.1 pH, Available P, Soluble Fe and Exchangeable Al

Coconut ash can be applying as liming agent that able to increase the soil pH especially in acidic soil. Herath (2014) approved that the soil pH was significantly increased in the coconut ash added treatment to the acidic soil. In addition, the treatment with added coconut ash has been able to bring its soil pH to a neutral level and maintained in a neutral range (7.06-6.91). This would be useful to make other major nutrients available as most macro nutrients increase their availability in the neutral pH levels. The K content and available phosphorus content significantly increased in coconut ash treatment due to the increase of pH to a neutral level (Herath, 2014). The phosphorus availability in soil is generally limited both in acidic and alkaline pH conditions. Thus, coconut ash has a greater potential of supplying potassium with providing additional advantages of increasing the availability of Mg and P, and also by enhancing soil pH to a neutral pH range (Herath, 2014). Baon (2009) reported that plant derived ash can supply essential nutrient elements to plants grown on nutrient deficient soils, beside its capacity as liming materials which is due to the very alkaline characteristic in pH.

General characteristic of the PDAsh is its very high pH around 12. Moreover, Masulili et al. (2016) also reported the soil pH was increased by the application of biochar from coconut waste to the acid soil. Coconut shell biochar and coconut husk biochar had a similar pH of 8.4 to 8.9 that indicate its ability as liming material to acid soils (Masulili et al.,2016). However, the application of biochar from coconut waste results in the lower rate of soil exchangeable Al and soluble Fe following the incubation experiment (Masulili et al.,2016).

Meanwhile, the soil available P was increase following the increase of soil pH as a result of liming by coconut waste biochar (Masulili et al.,2016). The increase on soil P following coconut waste biochar application also reported Wang et al. (2012) who found that biochar contained 70-80% of total P in an extractable form, which indicates the high availability of P in this particular coconut waste biochar. These decreases were undoubtedly due to the increase of CEC in the soil. The exchangeable Al and soluble Fe decreases as CEC increases. The improvement of the soil's physical properties, especially soil aggregation might also contribute to the lowering of Fe in acid soil (Masulili et al., 2010; Yuan and Xu, 2011). This soil structure improvement will make the soil condition more oxidative so the solubility of the Fe decreases.

2.7.2 Organic C, Total N, C/N Ratio and Nutrient Content

According to Bonneau et al. (2010), coconut ash is a very suitable fertilizer for peat soil. The coconut ash performed well when compared to a standard fertilizer primarily consisting of KCl. Coconut ash provides as much K and Cl as KCl, with nonlimiting contents for the other nutrients. Coconut ash therefore proves to be an effective K concentrator and its ash consequently has a virtually guaranteed minimum K rate. Potassium is a major plant nutrient taken up by plants through roots from soil. As potassium is associated with many functions in plants like transportation of nutrients, carbohydrates and water, if potassium is not adequately supplied, plant growth gets retarded (Oosterhuis *et. al,* 2013; Wakeel, 2013). Baon (2009) also proven that response of soil K content as affected by application PDAsh dosages both in was linearly positive. The present results indicated that higher dosages of PDAsh applied resulted in higher soil K content. The amount of K^+ ion in soil solution increased with higher application of K source treated. Similar result was obtained by Purba et al. (1992) on oil palm in which higher dosage of K fertilizer increased availability of K soil.

Application of PDAsh dosage improved K^+ ion amount in soil solution which then repulse position of Mn^{2+} ions from soil adsorption complex. Increased content of soil Mn was caused by soil pH. There was a positive response of soil Mg con centration in experiment to the dosage of PDAsh. It is commonly found that there is an antagonistic reaction between K and Mg. Increased concentration of soil K usually followed by reduction of soil Mg content. Sparks and Huang (1985) stated that increased concentration of soil K caused domination of K ion on exchangeable complex which may repel position of Ca and Mg.

According to Dibb and Thompson (1985), ratio of exchangeable Mg/K is a good indicator to predict a need for Mg nutrient considering the antagonism effect between K and Mg. Concentration of Ca in soil increased by application of PD Ash, except that of with dosage of 600 mg K_2O 2.5 kg^{-1} soil. The increased soil Ca concentration might be due the increased amount of Ca added to the soil, considering that PD Ash contained considerable amount of Ca.

Comparing with K, Ca in soil is not easily leached. Sparks and Huang (1985) stated that on soil adsorption complex, Ca is adsorbed more strongly compared to K. In addition, Masulili et al. (2016) investigated the effect of biochar made from coconut shell and coconut husk to improve the soil properties of west Kalimantan acidic soil. The coconut husk was characterized by a lower C content than the coconut shell, but contained higher concentrations of N, P and Na. The coconut shell contained a higher amount of Ca than the coconut husk. These chemical attributes were carried forward to properties of the respective biochars.

Conversely, the total C content was smaller in the coconut husk biochar than in the coconut shell biochar. The total soil organic C content was increased following the incubation of coconut waste biochar to the acid soils (Masulili et al., 2016). The addition of coconut shell biochar alone is responsible to the increase of soil total C reports by Novak et al. (2009). Moreover, Herviyanti et al. (2020) reported that application of coconut waste biochar improves the content of organic C, total N, and C/N ratio of Ultisols. According to Syuhada et al.(2016) suggested that the greater availability of C stimulates microbial activity, greater N demand, encourages immobilization, and recycles NO3-, and reducing the availability of N. Total N in the soil is organic N and minerals N in the form of ammonium (NH4+) and nitrate (NO3-) which are easily lost in the soil due to the process of ammonification, nitrification, washing, and evaporation. However, N leaching can be significantly reduced by applying coconut waste biochar to the planting medium (Mindari et al.,2018) and the C/N ratio shows the process of mineralization and N immobilization by microbial decomposers in organic matter (Herviyanti et al., 2020).

2.7.3 CEC and Exchangeable Cations

Awotoye et al. (2014) reported that six weeks incubation of 10 t/ha of ashed coconut gave the highest cation exchangeable capacity (CEC). The highest cation exchangeable capacity (CEC) values (4.66cmol/kg) was recorded in ashed coconutat 10 t/ha. The base saturation (BS) varied between 90.16 to 96.33 percent. The soil pH, OC and total N increased with increase in treatment levels in ashed coconut. This agrees with the findings of Katung et al. (1996) and Njoku and Mbah (2012), that organic amendment stabilizes soil pH by acting as buffering agent against undesirable pH fluctuations in soil. Awotoye et al. (2014) also found that phosphorus was relatively higher in ashed coconut. This may be attributed to the microbial activities which enhanced quicker mineralization. According to Molindo (2008), activities of micro-organisms and other agents encourage decomposition process. According to Herath (2014), soil exchangeable potassium, exchangeable Mg content was significantly higher in coconut ash treatment. The highest exchangeable K content of 3.8 meq/100g of soil was given by coconut ash treatment at 4 months after treatment application. These results show that the coconut husk ash has a great potential of supplying K and Mg.

Masulili et al. (2016) also reported that the CEC of coconut shell biochar and coconut husk biochar were considerably higher (16.79- 17.56 cmol kg^{-1}). The soil CEC was found to be increased in the coconut waste biochar incubated acidic soil. In acid soils, the soil CEC was correlated to the soil pH and an increase in soil pH will results in higher soil CEC. It is suspected that coconut waste biochar donates negative ions such as carboxyl groups. According to Syuhada et al. (2016) suggested that the oxidation of aromatic C and the formation of carboxyl groups was believed to be the main reason for the observed increase in CEC. Syuhada et al. (2016) also reported that many negative charges were not expressed in the soil because it was pH-dependent and most negative charge sites were blocked by interactions with Al. The base content (Ca, Mg, and K) have increased along with the increase in CEC. Furthermore, the addition of coconut waste biochar into the soil shows an increase in the availability of basic cations and concentrations of P and N (Rawat et al*.,* 2019).

2.8 Palm Kernel Shell Biochar

2.8.1 General Overview

Solid oil palm biomass residues are generated throughout the year in palm oil mills and oil palm plantations. In 2014, about 4.46 million tonnes of PKS residues in Malaysia were produced which increased to 4.56 million tonnes

(Abd Wafti et al., 2017) in 2015 and 4.72 million tonnes in 2016 (Loh, 2017). Palm kernel shell (PKS) is one of the solid oil palm biomass residues that has the highest commercial utilization value. Palm kernel shells (PKS) are hard, carbonaceous, organic by- products of the processing of the palm oil fruit. According to Vijaya et al. (2008), the palm kernel shells (PKS) can be used for energy production through gasification or combined heat and power (CHP). However, only approximately 45% of PKS is utilised with the remainder sold as fuel to external parties. Owing to the high lignin and fixed carbon content of original PKS (Abnisa et al., 2011; Choi et al., 2015) conversion of PKS to carbon-negative biochar appears to be a promising alternative. After gasification, some PKS remains as charred residue that can be convert into biochar (Bazargan et al., 2014). PKS is high in lignin content (47.3%-50.7%) which is essential for thermal conversion into biochar (Choi et al., 2015; Kataki et al., 2015; Loh, 2017). Bazargan et al. (2014) reported that the palm kernel shell biochars (PKSB) show very high calorific value exceeding typical values for biomass. Its particle size of about 1.5 cm is suitable to be loaded directly into any design of pyrolysis reactor without further downsizing and pre-treatment.

2.9 Production of Biochar

2.9.1 Gasification

Gasification is a thermochemical partial oxidation process converting carbonaceous materials such as biomass, coals, and plastic materials to gaseous products using gasification agents (air, steam, oxygen, CO_2 or gas mixture). Gaseous products (H_2, CO, CO_2, N_2, etc.), liquid products (tar and oil), and solid products (char and ash) are formed in a gasification process. Gasification is aimed at producing gaseous products, thus the yield of biochar is only approximately 5% to 10% of the raw biomass material mass which is lower than that of fast pyrolysis about 15% to 20% (Mohan et al., 2014; Brewer et al., 2009). The char produced during the pyrolysis step is converted to CO, CH_4, and H_2 through various gasification reactions. The parameters affecting the gasification reactions include the reaction temperature, gasification agent type, gasification agent–biomass ratio, and pressure. Taba et al. (2012) suggested that the temperature is the most important among the parameters directly affecting the gasification reactions. They reported that increasing temperature enhanced the production of H_2, CO, and carbon, while reducing the contents of CO_2, CH_4, hydrocarbons and tar. Gomez-Barea et al. (2013) also reported that the reduction of the gasification temperature in fluidized bed gasification resulted in reduced carbon conversion and an increased tar concentration in gas. Carbon conversion as well as the composition and heating value of the product gas also varies according to the gasification agent used in the gasification process. Tay et al. (2013) examined the effects of gasification agents on the characteristics of the char using a reducing gasification agent (H_2O) and oxidizing gasification agents (CO_2 and O_2). The ratio of the small and large aromatic ring structure of the aromatic compounds composing the char was lower and the contents of alkaline metals such as Mg and Ca in char were higher when H_2O was used. The mechanism of gasification can be divided into several steps.

Drying + Pyrolysis + Oxidation= Combustion + Gasification

2.10 Physical and Chemical Properties of Palm Kernel Shell Biochar

2.10.1 Physical Properties

PKS consists of small size particles, medium size particles and large size particles in the range 0-5mm, 5-10mm and 10-15mm (Alengaram et al., 2010). OPKS is an organic aggregate that contains many pores and hence the water absorption is high. Depending on the species of the trees and matured age of OPKS, the 24 hours water absorption varies in the range of 14% to 33% (Alengaram et al*,* 2013). The PKS constituent components of lignocellulosic materials consist of 27.9wt% cellulose, 45.7wt% hemicellulose and 54.3wt% lignin (Rahman *et.al,* 2016).

2.10.2 Carbon Content

High carbon content in PKS biochar is also important as a carbon sequestration in soil application. Many studies have shown that the biochar is ideal to use in soil amendment as a carbon's sequestration (Duku et al*.,* 2011; Galinato et al*.,* 2011). Basically, the carbon content in the original biomass is easy to degrade due to the low grade of carbon content. Nevertheless, the carbon content in the biochar has ability to stable for long time period due to the pyrogenic carbon formed as reported by Shenbagavalli and Mahimairaja (2012). The stable structure of carbon in biochar was obtained due to the heat treatment during the carbonization process via gasification. It is enabled to stable for long time period when it being applied for low temperature application such as a soil amendment in agriculture activities. Thus, huge quantity of carbon is being stored in biochar to avoid carbon release into atmosphere. As claimed by ZeroPoint Clean Tech Inc. Company (2013), each ton of biochar produced represents approximately 3.5 tons of carbon dioxide removed from the atmosphere. When KPS biochar is continuously produced, it results in the decrease of carbon footprint in atmosphere thereby reducing the greenhouse gases effect for the greener environment.

2.10.3 Physic-chemical processes

Many studies have found that Palm Kernel Shell (PKS) biochar can mitigate global warming (Shepherd et al*.,* 2009; Woolf et al*.,* 2010), help plants to access more nutrients through physic-chemical processes that allow for better utilization of “soil inherited” or ‘fetiliser-derived’ nutriets (Sohi et al*.,* 2009), improve soil pH and permeability of loamy soils (Martinsen et al., 2014).

2.11 Benefit Use of PKS Biochar toward Growth Media and Plant

iochar application has a strong positive effect on productivity and yield such as increasing CEC, nutrients availability, water and nutrients retention, and improved crop yields. In a study of durum wheat cultivation, biochar application resulted in positive yield response, with biomass enhancement of up to 324% (Vaccari et al., 2011). This is similar with the results obtained in other studies done with other crops in other places (Glaser et al*.,* 2002).

Generally, indirectly (Lehmann et al., 2003; Steiner et al*.,* 2007). Some studies have reported biochar. In a cropping trial in Amazon Basin archaeological

Anthrosol soils with high carbon contents and Ferralsols with added biochar, a significant increase in nutrients availability such as phosphorus, calcium, manganese and zinc were obtained. These increased nutrients availability resulted in 38% to 45% increase in biomass of the two crops in Anthrosol (Lehmann et al., 2003). In another study carried out by Kimetu et al. (2008), These effects may also act in concert to result in improved crop performance and single fruit weight are tabulated in Table 2.7. In general, the 3% and 5% biochar rates resulted in significant increases for all parameters. Results of experiment with doses (Table 2.8). Total pepper fruit yield per plant and single fruit weight were also doses (Table 2.8). Total pepper fruit yield per plant and single fruit weight were also significantly outperforming the 1% treatment (Table 2.8). Tomato plant bud, flower and fruit yields did not exhibit significant effects of biochar.

Table 2.6 : Effect of biochar amendment on bud and fruit formation in pepper

Biochar (wt %)	Buds (number plant^{-1})		Set fruits (number plant^{-1})	Fruit weight	
				Whole plant yield (g)	Single fruit (g)
	Time after planting (days)				
	32	**37**	**44**	**57**	**57**
0	13.5±0.4b	15.0±1.1b	3.0±0.9 b	440.0±21.1b	83.3±7.2b
3	17.5±1.0a	17.5±1.5a	5.2±1.1 ab	565.0±36.1b	97.2±4.6a
5	17.5±1.7a	17.5±2.1a	7.2±0.9 a	732.0±58.5a	104.8±4.2a

(Source: Graber et al., 2010)

Table 2.7 : Effect of biochar amendment on bud and fruit formation in pepper

Biochar (wt %)	Buds (number plant^{-1})	Mature fruits (number plant^{-1})	Fruit weight	
			Whole plant yield (g)	Single fruit (g)
Time after planting (days)				
	54	**64**	**64**	**64**
0	3.6 ±0.8 b	2.0±0.6 b	201.4±25.8c	99.1±3.0 b
3	6.9 ±0.7 a	3.1 ±0.5 a	359.6±29.2b	115.1±4.4ab
5	7.4 ±0.4 a	5.5±0.9 a	662.5±112.0a	119.7±2.1 a

(Source: Graber et al., 2010)

2.12 Soil Fertility Improvement Method by Application of PKS Biochar

2.12.1 pH, EC, Available P, and Exchangeable Al

Major et al. (2010), Gaskin et al. (2010), Yuan and Xu (2011), Alburquerque et al. (2014), Chintala et al. (2014), Yao et al. (2019) have reported substantial increase in soil pH by the biochar treatment. Biochar is carbon rich material obtained by pyrolysis of biomass with little or no oxygen (Lehmann and Joseph, 2009). Pyrolysis of plant biomass normally results highly alkaline biochar (Lehmann and Joseph, 2009; Laird et al., 2010; Yuan and Xu, 2011). However, alkalinity varies with respect to feedstock properties used for the biochar production. Greater the alkalinity of biochar, greater is the reduction in acidity (Yuan et al., 2011). This has been attributed to the liming potential of biochardue to high inherent pH of biochar, base cation content, $CaCO_3$ content and calcium carbonate equivalent (Gaskin et al., 2010), Chintala et al., 2014). Novak et al. (2009) also reported the increase of soil pH following biochar application to acid soils and this was attributed to the liming ability of biochar.

The active pH expresses H^+ concentration in soil solution and potential pH expresses H+ concentration in colloidal soil. An increase in pH is due to the contribution of OH- from biochar. The alkali nature of biochar is formed from H+ ions which can be exchanged with the surrounding soil, thereby causing an increase in soil pH with the application of biochar (Madhavi et al*.,* 2017). Shetty and Prakash (2020) indicated that increase in pH with the application of biochar is due to high pH and EC indicating higher soluble salts, greater CCE and Ca content. Biochar application resulted in neutralization of soil acidity by series of proton consumption reactions as reported by Yuan and Xu (2011), Chintala et al*.* (2014). McBeath and Smernik (2019) reported faster mineralization and degradability of biochar produced at lower temperature. Moreover, significant increase in soil EC with biochar application has often been reported in previous studies (Gundale and DeLuca, 2007; Chan et al*.,* 2007; Alburquerque et al., 2014; Chintala et al., 2014; Berek et al., 2018).

According to Shetty and Prakash (2020), increasing trend in soil EC was noticed by biochar application under Al treated soil. Further, basic cations present in biochar might have solubilised into the soil solution under highly acidic pH resulting net increase of soil EC. Recent studies indicate that liming effect of biochar, adsorption properties and the surface adsorption and co-precipitation of Al with silicate particles to fix Al in soil (Qian et al*.,* 2013; Qian et al*.,* 2016). Similar result found by Shetty and Prakash (2020) when bio-char application to Al treated soil reduced the soluble and exchangeable Al. According to Qian et al*. (*2013), increase in biochar rates can multiply its liming effect leading to strong adsorption of Al monomers and further conversion of toxic Al^{3+} to less toxic Al(OH)3 and Al(OH)4-. Qian et al. (2013) also reported that the biochar's adsorption and precipitation capacity plays greater role in Al toxicity alleviation compared to its alkalinity.

Complexation of Al with organic hydroxyl and carboxyl groups or the surface adsorption and co-precipitation of Al with silicate particles in biochar are reported as effective mechanisms. Ch'ng et al. (2014) reported that biochar treatment increased the P availability especially in the P deficient soil of the humid tropics. Biochar is capable of increasing the soil P availability through either its direct inputs or its retaining potential of P applied (Zhao et al., 2016). The surface property, such as the microporous structure of the biochar, has been demonstrated to determine its capacity in P adsorption (Chan et al., 2007).

2.12.2 Organic C, Total N, C/N Ratio and Nutrient Content

Azlan Halmi et al. (2018) reported that increases of total organic C in biochar treated soil revealed that biochar contributes to the organic C pool in the soil. The result of organic C is in agreement in many findings that showed a significant increase of the total organic C pool in the soil environment (Hernandez-Soriano et al*.,* 2016). Despite the palm kernel shell biochar comprised of higher initial total C and N. Greater organic C concentrations may lead to the elevation of soil microbial activity, causing higher N demand in soil, hence immobilized and reduced available N for plant (Burger and Jackson, 2003). Although made up recalcitrant C with high stability, biochar comprises small fractions of readily mineralized labile active C, which is bioavailable for microbial utilization and serves as a substrate (Farrell et al., 2013). Azlan Halmi et al. (2018) found that enhancement of microbial biomass N status of soil in palm kernel shell biochar with fertilizer treatment indicate a strong stimulation of biochar in combination with the fertilizer.

This finding indirectly points out the mineralization of N by microorganisms due to the fertilization input. Amendment of fertilizer reduced the C:N ratio of soil and hence stimulated N mineralization as supported by the result of NH4+-N concentration in palm kernel shell biochar. PKS biochar has also been shown to increase the fertility of soil resulting in decreased need for fertilizers and irrigation. Moreover, the use of biochar for soil amendment application can also stimulate the mineralization, reduce the nitrous oxide (N2O) emission, reduce the ammonia (NH4) and nitrate (NO3-) losses to offer a mechanism for developing slow release fertilizers as reported by Clough et al.,2013.

Thus, the biochar use insoil application is proposed to improve the soil quality as well as to act as a carbon sequestration method to reduce carbon footprint for greener environment. Besides, burnt PKS may improve soil fertility by providing nutrients such as magnesium and potassium. Chen et al. (2000) reported that the size of the microbial biomass P is directly associated with the availability of P to plants. In fact, the microbial biomass P can be re-mineralized in a short turnover period (Achat et al., 2010), consequently serving as an available P for plant (Achat et al., 2010). Azlan Halmi et al. (2018) found a strong stimulation of soil microbial population density by palm kernel shell biochar. The heterogeneous characteristic of biochar such as the porosity serve as a colonizing site for microbiota and acting as a potential habitat (Jaafar et al., 2014). Biochar was also discovered to be an ideal ecological niche that allowing microorganisms to establish themselves on the pores and surfaces, retain readily metabolized nutrient (Cornelissen et al., 2005) and substrate (Warnock et al., 2007), thus stimulating the total size of soil microbial population

2.12.3 CEC and Exchangeable Cation

According to Madhavi et al. (2017), biochar has a high cation exchange because it has a high surface area capacity, which leads to an increase in soil pH and water holding capacity, and affinity for micro and macronutrient plants. Biochar addition clearly improved tropical soil properties in general. Improvements of soil pH and CEC on acidic tropical soil after biochar treatment were in agreement in many biochar experiments, either in a pot or field study (Ch'ng et al., 2014; Alling et al., 2014). Shetty and Prakash (2020) indicated that the reduction of exchangeable acidity of soil clearly indicates the ability of biochar's to decrease the exchangeable Al^{3+} and H^{+} in soil solution. Free bases present in biochar such as Ca, magnesium (Mg) and potassium (K) can be readily released into to the soil solution resulting in net increase of soil pH and exchangeable bases (Shetty and Prakash, 2020).

Such observations were also noticed by Lehmann et al. (2003) and Chan et al. (2007). Shetty and Prakash (2020) also reported that significant increase in Ca was noticed by biochar treatments under Al treated soil. Similar trend was reported by Silber et al. (2010) in a study on kinetics of release of Ca from corn straw biochar that the Ca release was increased as pH decreased. Addition of biochar to nutrient poor soil has been reported to enhance nutrient availability and increase plant biomass (Alburquerque et al., 2014). High surface charge density, large surface area and internal porosity, and presence of both polar and non-polar surface sites on biochar play a vital role in metal adsorption along with the liming effect (Laird et al*.,* 2010). Therefore, incorporation of biochar into acid soil could help to mitigate soil Al toxicity by decreasing soil exchangeable acidity, increasing soil exchangeable base cations, and thereby improving soil fertility.

2.13 Chilli Pepper

Chilli pepper (*Capsicum annuum* L) is belonging to the *Solanaceae* family which represents a diverse plant group (Harini and Sita, 1993; Prakash et al*.,* 1988; Marín et al*.,* 2004; Garcés-Claver et al., 2007; Liefting et al., 2009). Table 2.9 shown the details about taxonomy of *Capsicum annuum.*

Table 2.8 : Taxonomy of *Capsicum annuum*

Capsicum annuum Scientific classification	
Kingdom:	Plantae
Order:	Solanales
Family:	Solanaceae
Genus:	*Capsicum*
Species:	*C. annuum*
Binomial name *Capsicum annuum* L.	

(Source: Eshbaugh, 2012).

Chilli is believed to have been introduced to India by Portuguese explorers (Singh et al*.,* 1993; Basu and De, 2003) and North Eastern India by Christian Missionaries (Dhaliwal and Jindal, 2014). India has become world's largest producer and exporter of chilli (Sanyal et al*.,* 2008; Jagtap et al*.,* 2012). Pungency in chillies due to Capsaicin and its analogues, collectively called *Capsaicinoids* (Stewart et al*.,* 2005; Reilly et al*.,* 2001; Tanaka et al*.,* 2009). *Capsicum* plant is economic, cultural and biological importance due to the use of the fruits preparing dishes of typical culinary traditions (Aguilar- Meléndez et al*.,* 2009; Lee et al*.,* 2008). Chilies are excellent sources of vitamin A, B, C and E with minerals like molybdenum, manganese, foliate, potassium, thiamine and copper

(Bajaj et al*.,* 1979; Chuah et al*.,* 2008; Vega- Gálvez et al*.,* 2009). According to Norziah and Ching (2000), Malaysian red chilli was found to be very nutritious, with high vitamin C (175mg/100 g), calcium (15mg/100 g), fiber (4.8%), protein (2.8%), iron (1.8mg/100 g), ash (0.9mg/100 g), and lipids (0.7mg/100 g) as shown in Table 2.10. Mature pepper fruits are rich in carotenoids, compounds with antioxidant and anti-carcinogenic capacity, while either immature or mature fruits contain a high concentration of antioxidant phenolic compounds.

Table 2.9 : Comparison of beneficial elements in different foodstuffs

Foodstuffs	Vitamin C	Ca	Fe	Ash	Lipids	Protein	Fiber
	(mg/100 g)				(%)		
Red chilli	175.0	15.0	1.8	0.9	0.7	2.8	4.8
Seaweed (G.changii)	28.5	651.0	95.6	22.7	3.3	6.9	24.7
Green bean sprouts	14.1	25.0	1.7	0.3	0.2	2.6	0.7
Soyabeans, white	7.5	200.0	6.0	4.8	18.9	33.8	5.5
Peas (green, canned)	8.1	25.0	1.9	1.3	0.4	3.4	2.7
Red spinach	48.3	120.0	4.0	1.8	0.3	2.8	1.5
Carrots	9.5	140.0	0.8	0.8	0.1	1.0	1.1
Broccoli	85.0	40.0	0.7	0.8	0.1	4.1	1.0
Lettuce	27.6	50.0	1.5	0.7	0.1	1.2	0.5
Tomato	25.8	12.0	0.8	0.6	0.2	1.4	0.5
Red pumpkin	36.5	21	0.7	0.4	0.1	0.9	0.3
Cabbage	53.0	40	0.6	0.8	0.2	1.6	0.9

(Source: Norziah and Ching, 2000)

Chilli is an annual herbaceous crop that reaches a height of one meter and has glabrous or pubescent lanceolate leaves with white flowers and fruits with varied, colour and pungency. Chilli plant requires a warm and humid climate for its best growth and dry weather during the maturation of fruits. Chilli grows best at 20 - 30°C. It can be grown in higher altitude up to 2000 meters above the sea level (Walters and Jha, 2016). It can be grown successfully as a rain-fed crop in areas receiving an annual rainfall of 850-1200 mm and a soil pH of 4.3-8.7. Capsicum species are cold sensitive and generally grow best in well drained, sandy/silt-loam soil. Plantings are established by seeding or transplanting. Usually flowering usually occurs three months after planting. High temperature associated with low relative humidity at flowering increases the transpiration resulting in shedding of buds, flowers and small fruits (Rammohan et al*.,* 2003).

The crop duration of chilli is about 150 to 180 days depending on variety, climate, fertility and water management. By referred to Norman (1992) paper, chilli is a small perennial shrub characterized by white or greenish-white corolla, one or more pedicels at a node with varying fruit sizes and shapes. The pepper can also be distinguished by its pungency which varies with cultivar. Pepper grows relatively quick with a maturity period of 3 to 4 months. The growth of chilli consists of vegetative and reproductive phases. Vegetative phase in chilli extends to 75 to 85 days followed by 75 to 95 days of reproductive phase. The vegetative phase is characterized by increase in plant height with branching. Flowering starts from 80 to 85 days of the crop or 40 to 45 days after transplanting. Rajput et al. (1998) state that the chilli plant is cross pollinated crop with 50% of natural crossing, then fruit development and maturity about 40 days' time is required after anthesis and pollination.

The paper also reveals that the pepper plants will grow best at temperatures in range of 20 to 25 °C. Pepper plants are damaged at temperatures above 32°C and below 5°C (Berke et al., 2005). Soil moisture should be at 65-70% for optimal vegetative and reproductive processes. The chilli is a plant of dichotomous branching and its root can reach alongdepths between of 70cm to 120cm. The bulk of the roots is located within a soil depth of 5 to 40 cm. The plants have a green cylindrical herbaceous main stem thatis semi woody at the base and slightly pubescent. The growth of the stem is limited,and the stem divides into 3 or 4 branches or secondary stems between the heights of10 and 40 cm. The flowers appear solitary in the node of branches of the stem, and each branch can have 5 to 6 or more flowers. During the early stages of growth, the fruit appears round and the calyx covers much of the outside. Fruits are usually consumed when they reach maturity at 60 to 78 days after pollination (DAP) and have been dehydrated (Víctor et al., 2017).

2.14 Fertilizer Consumption by Chilli in Malaysia

The Malaysian farming sector is still dependent on agrochemicals including chemical fertilizers and pesticides. These agrochemicals while playing an important role in sustaining the needed yields and ensuring adequate profit levels to producers inevitably lead to increasing environmental damages (such as aquatic biodiversity) and food safety issues. In addition, the substantial agrochemical subsidies provided to the paddy production sub-sector render the use of such inputs inefficient. In the longer-run, it results in even more intensive use of chemical-based inputs as the natural soil base further erodes. Mineral fertilizers constitute more than 90% of fertilizer consumption in Malaysia. Mineral fertilizers account for more than 90 percent of fertilizers used by all types of farming systems in Malaysia. The main fertilizers are urea, ammonium sulphate, calcium ammonium nitrate, phosphate rock, super phosphates, ammonium phosphate, potassium chloride, potassium sulphate and NPK, NP and PK compound fertilizers. Due to the rapid expansion in crop production, especially of plantation crops (rubber, oil palm and cocoa) there has been a corresponding increase in fertilizer use. Potassium fertilizers have shown the largest increase. This large increase in the use of potassium fertilizer is due to the continued expansion of oil-palm cultivation, which requires significant amounts of this nutrient. Fertilizer use on each crop was estimated from recommended fertilizer rates, the expected yields and actual yields per hectare. According to these calculations, the estimated fertilizer nutrient consumption for each of the groups of crops as refer to Table 2.11. According to the Table 2.11, on average in 2000 and 2001, the industrial crops accounted for 96 percent of total nutrient use, fruit crops for 3 percent, vegetable crops for 0.3 percent, cash crops and spices for the remainder. Paddy is included in the group of industrial crops. The estimated total nutrient consumption on paddy amounted to 63 500 tonnes nutrient in 2000 or 2001, 5.6 percent of the total of industrial crops, 5.4 percent of all crops.

The veget;able crops in total occupied 12 682 ha (0.002 percent) of the total cultivated area in Malaysia in 2001. This report focuses on six vegetable crops, Chinese spinach, lady's fingers, chili, long bean, cucumber and tomato. A summary given in Table 2.12 shown that chili was the largest consumer of fertilizer and Chinese spinach the smallest. According to Vimala et al. (2007), chilli is one of the challenging crops by farmer and high fertilizer consumption need in chilli growth and production. So, the farmers choose to use high doses fertilizer to meet the nutrient requirements. Each planting seasons, farmers use K fertilizer as much as 150 to 180 kg ha^{-1} K2O or KCl 250 to 300 kg ha^{-1} (Nurlenawati et al*.,* 2010). The farmer's use of Urea was much higher than the recommended dose. To cultivate chili in 1 ha of land the recommended doses of fertilizers were 31-60 kg N, 21-40 kg P, 31-60 kg K and 6-10 kg S in medium quality soil. In low quality soil, recommended doses were 61-90 kg N, 41-60 kg P, 61-90 kg K and 11-15 kg S. Chilli consumed NPK fertilizers for growth and production about 3.6 thousand tons to 5.36 thousand tons of nutrient from 2002 to 2008, and expected to be increase from year to year (Sabri, 2009). According to Hafif and Wardani (2005), the continuously application of chemical fertilizers in high doses and frequently will causing the decrease in productivity, land resources quality and environmental pollution. Hafif and Wardani (2005) also reveals that nutrients excess that not utilized by plants can turn into pollutants and lead to nutrient imbalances and in turn declining plants response. The key factors for improving the productivity of agricultural lands is use the appropriate fertilizer doses according to plant requirement and soil nutrient availability. Meticulous fertilizer management techniques are required for producing high yield and good quality of chilli.

This is true for N and K which directly influence growth, maturity, and yield and fruit quality. Chilli has also been shown to respond very well to application of fertilizer (Akande et al*.,* 2008) and produced well when it is adequately supplied with the essential nutrients (Peck and MacDonald, 1975). Aliyu et al. (1991) reported that day to 50% flowering, maturity days, number of fruits per plant, fruit diameter and length of chilli was significantly affected by fertilizer application. Optimum dose of fertilizers increases the proper growth, development and maximize the yield of sweet pepper. A large amount of fertilizers is applied every year in Malaysia to achieve maximum productivity of chilli and to meet the growing demand (FAO, 2010). This is a major environmental and health concern considering the deleterious impact of these chemical compounds on terrestrial and aquatic ecosystem nitrogen(N), potassium(K) are the primary nutrients that in excessive amounts pollute our lakes, streams, and wetlands. High yields of Capsicum have been obtained in the tropics mainly through the use of improved genotypes, fertilizers and good cultural practices (Saha et al*.,* 2010).

Inorganic fertilizers are relying to improve crop yields and maintain soil fertility. However, the wide use of these fertilizers is hampered by their high costs, and the highly variables vegetables crops responses under small scale farming. Fertilizer is one of the major factors of crop production especially the nitrogen is more essential for good plant establishment and expected growth because the productivity of pepper is highly responsive to N fertilizer. Moreover, Tumbare et al. (2004) reported that nitrogen fertilizer increased yield, the fruit weight and fruit number of chili peppers. Qawasmi et al. (1999) also reported that when increasing the rates of nitrogen applied in pepper plants can increases the uptake of nitrogen by the plants, stimulated the uptake of potassium and phosphorus through the synergistic effect of nitrogen on them. Potassium uptake also depends on plant factors, including genetics and developmental stage (vegetative versus reproductive stages (Rengel et al., 2008). The application of optimum dose of fertilizer is important to increase the pepper growth, development and maximize the yield of pepper. The three different frequencies of application recommended by (Leong and Lee, 1993) were all in basal, 1/2 in basal and 1/2 at 60 days after transplanting, 1/4 in basal and 1/4 each at 30, 60 and 90 days after transplanting (common practice). Application of N in four splits at 30-day intervals has been recommended by Sigh (1988) to achieve maximum yields and profits in chilli production. Subhani et al. (1990) obtained thehighest yield of chilli when both N and K were applied in four splits at planting 30,60 and 90 days after transplant (DAT).

Table 2.10 : Fertilizer nutrient consumption by crop groups

Crop	N			P2O5 ('000 tonnes)			K2O		
	2000	2001	2002	2000	2001	2002	2000	2001	2002
Industrial crops	319	331	334	333	348	348	468	481	478
Fruit crops	11	11	14	11	11	14	14	14	18
Vegetable crops	1.2	1	1.1	1.2	1.1	1.1	1.7	1.5	1.6
Cash crops	1.2	1.1	0.8	0.6	0.6	0.5	1.3	1.2	0.9
Spices	0.5	0.5	1.2	0.2	0.2	0.6	0.6	0.7	1.7
Total	333	345	351	346	361	364	486	498	500

(Sources: Departments of Agriculture Malaysia, 2015)

Table 2.11 : Vegetable crops summary of total fertilizer use (excluding Sabah and Sarawak)

Crop	N			P2O5 ('000 tonnes)			K2O		
	2000	2001	2002	2000	2001	2002	2000	2001	2002
Chinese spinach	81	93	107	81	93	107	115	132	152
Lady's fingers	150	124	124	150	124	124	212	175	176
Chili	361	351	302	361	351	302	511	497	428
Long bean	188	180	181	188	180	181	266	255	256
Cucumber	147	134	131	147	134	131	208	190	186
Tomato	282	192	275	282	192	275	400	271	389

(Sources: Departments of Agriculture Malaysia, 2015)

2.15 Fertigation System

Many studies on the technologies to develop a sustainable cultivation system with efficient resource use while limiting environmental degradation have emerged to increase crop productivity. Fertigation system is one of important in soilless culture. Soilless culture system under protected structures is one of the technologies that had been used sporadically throughout the world over the last several decades to increase vegetable production. It is used for commercial production of high value vegetables with high rate of economic return such as chilli, bell pepper, tomato and cauliflower in solid media other than soil or in aerated nutrient solution (Gruda, 2009; Pardossi et al., 2011; Hussain et al., 2014).

This growing system appears to be an alternative for conventional soil cultivation (Razi, 1994). The shift from conventional soil-based cultivation into substrate as growing medium in soilless cultivation was mainly to reduce the problem of soil borne diseases, soil exhaustion, unfavorable soil compaction, poor drainage and high soil salinity (Albaho et al., 2009; Sengupta and Banerjee, 2012; Lorenzo et al., 2013). Soilless culture offers many benefits such as efficient utilization of space where crop can be grown in a limited space, improve water and nutrient absorption thus increase water and nutrient use efficiency, minimize the nutritional ions discharge and pesticide residue thus conserving freshwater reservoirs, and produce high quality products with high yields (Ismail, 2000; Raviv and Lieth, 2009). The drawback of this system such as high initial expenditure for protected structures and irrigation system as well as needs of technical knowledge for complicated cultivation procedures can be overcome by using locally available materials (Asaduzzaman et al., 2015).

In soilless culture, containers filled with substrate are used as a substitute of soil to retain water and nutrient, provide aeration, allow maximum root growth and physically support the plant (Benedetto, 2007; Olle et al., 2012). The selection of substrate for commercial cultivation is based on its availability, cost and local experience (Pardossi et al., 2011). Based on the studies conducted to determine suitable types and mixture of substrate, coconut coir dust which is derived from coconut (*Cocus nucifera* L.) husk fiber processing industry is available organic substrate for soilless culture production due to its physical and chemical properties (Awang and Ismail, 1997; Abad et al., 2002; Nazari et al., 2011; Suhaimi et al., 2012; Rahimi et al., 2013)

2.16 Conclusion

In summary, the literature review on the effects of media mixtures derived from selected agricultural wastes for enhancing nutrient uptake efficiency, growth, and yield performance of chili under a fertigation system reveals a growing body of research indicating the potential benefits of sustainable agricultural practices. The studies reviewed consistently highlight the positive impact of utilizing media mixtures incorporating agricultural waste materials on the overall health and productivity of chili plants. These mixtures contribute to improved nutrient availability, enhanced root development, and subsequently, increased yield. The reviewed literature underscores the importance of careful selection and balanced combinations of agricultural waste components to achieve optimal results. Additionally, the findings emphasize the broader implications for resource efficiency, environmental sustainability, and the promotion of eco-friendly farming practices. Despite the overall positive trends, variations in methodologies and specific agricultural waste combinations suggest the need for further research to establish standardized practices and address specific crop and environmental contexts. The literature collectively contributes to the foundation of knowledge essential for implementing effective, sustainable, and economically viable fertigation systems in chili cultivation.

CHAPTER 3

GENERAL MATERIALS AND METHODS

3.1 Soilless Growth Media

3.1.1 Preparation of Soilless Growth Media

The agro-wasted soilless growth media were prepared by different ratio by part (v/v) from material coconut coir-dust, coconut shell ash, and PKS biochar as shown in Table 3.1. Growth media T1, T2, and T3 were containing with 1 full part or 100% of each material. Meanwhile, T4, T5,and T6 were containing of 1 part of coconut ash combined with different ratio of coconut coir-dust (3:1, 2:1, and 1:1), as well as T7, T8 and T9 were containing of 1 part of PKS biochar combined with different ratio of coconut coir-dust (3:1,2:1,1:1) shown in Table 3.1 respectively to a broader selection for the fertigation practices study includes a diverse sample that reflects the of interest.

Table 3.1 : Agro-wasted soilless growth media ratio

Growth Media	Ratio(v/v)		
	CCD	CA	PKSB
T1	1	-	-
T2	-	1	-
T3	-	-	1
T4	3	1	-
T5	2	1	-
T6	1	1	-
T7	3	-	1
T8	2	-	1
T9	1	-	1

3.2 Laboratory Media Analysis

The physico-chemical properties of particle size, bulk density, particle density, porosity, water retention, and nutrient retention in soilless growth media were recorded before and after the experiment. Meanwhile, the chemical properties of pH, electrical conductivity, total organic carbon, nitrogen and sulfur, CEC and exchangeable bases, and nutrient content in soilless growth media were recorded before and after the experiment.

3.2.1 Particle Size

The particle size of media was determined by Sieving method (Pope and Ward, 1998). Sieve analysis is a technique used to determine the particle size distribution of a media. This method is performed by sifting a media sample through a stack of wire mesh sieves, separating it into discrete size ranges.

3.2.2 Bulk Density, Particle Density, Porosity

The direct method-core sampling (Abu-Hamdeh and Al-Jalil, 1999) was used to indicate the bulk density. The ring sampler was weighed and recorded. The media was fully filled inside the core and carefully trimmed flush with the edge at both ends by using a spatula. The media was transfer from the cylinder to the weighed aluminum can and cut into small pieces. The weight was recorded (W_1). Then, the media was placed into the oven to dry at 105°C and weighed the dried media (W_2).

$$\textit{Bulk density } (g/cm^3) = (W_1 - W_2) / \textit{volume}$$

The particle density was defined by Picnometric method (Mohsenin, 1986; Leege and Thompson, 1997; Annan and White, 1998). The pycnometer flask with glass stopper was weighed (M_1), then half full of media was filled in the flask and weighed again (M_2). Then, water was added slowly, mixing soil and water thoroughly by vigorous shaking until the flask was full and weighed (M_3). After that, the entire contents were poured out, and only water was refilled inside the flask with stopper (M_4). The calculation for determined the particle density was shown below.

$$\textit{Particle density } (g/cm^3) = M_2 - M_1 / [(M_4 - M_1) - (M_3 - M_2)]$$

Meanwhile the porosity was the direct calculation of bulk density and particle density (Casanova et al. ,2016).

$$\textit{Porosity} = 1 - (\textit{bulk density} / \textit{particle density}).$$

3.2.3 Water Retention

The water retention or water holding capacity of soil was determine by Ceramic pressure plate method as shown in Plate 3.1 (Richards, 1948; Fredriksson and Johansson, 2016). The cellulose membrane was placed on porous porcelain plate in the instrument. The pre-weighed amount of media sample was filled into the retainer rings in the instrument, then the plate was filled with water to wet the sample (0 kPa) from below and allow it to soak overnight. After that, the excess water was removed after the sample was saturated with water, and the instrument was closed and tighten it with the screws. The sample in the instrument was applied by four different pressures were 1kPa, 10kPa, 33kPa (field capacity), and 1500kPa (permanent wilting) until no more water is forced out of the sample. This experiment was taking about 4 days. The weight of the container with and without the moist of sample was recorded. Then, the moist sample was dried in a forced-draft oven at 105°C for 24 hours, and the moisture content was calculated as percentage of oven-dry weight of sample.

3.2.4 Nutrient Retention

The nutrient retention was determined by incubation and leaching method (Sartain et al., 2004; Canali and Benedetti, 2006). About 20.0grams was weighed and pour inside the container (150.0mm length x 150.0mm width x 70.0mm height). The hole was making at the bottom of the container to allow the access fertilizer leached down. Then, the media was incubated for 6 different days (1 day, 3 days, 6 days, 9 days, 12 days, and 15 days) by apply the chemical AB fertilizer about 2ml for thrice times daily (6ml every day). The amount of excess collected solution (leachate) was recorded. Then, the sample was analyses by using Inductively coupled plasma optical emission spectroscopy (ICP-OES) to determine the nutrient content for each different day.

3.2.5 pH and Electrical Conductivity

The soil pH and electrical conductivity were measured electrometrically in water at 1:1 soil/water ratio using pH/EC meter (Hogg and Henry, 1984; Khorsandi and Yazdi, 2007). The media was determined by using Electrode pH meter (Model Lab CHEM- CP, Japan) in solution of its suspension. The ratio of the mixed growing media to water was 1: 2.5 (v/v). About 10.0grams of media was weighed and put into the plastic vial. Then, 25 ml of distilled water was poured into plastic vial containing soilless media. Then, the plastic vial was shaken for 1 hour and leaved for overnight. After 24hours, the pH and EC were recorded using a digital Electrode pH/EC meter (McLean, 1982).

Plate 3.1 : pH meter (Model LabChem-CP, Japan)

3.2.6 Total Organic Carbon, Nitrogen, and Sulfur

The total organic carbon, nitrogen and sulfur were determined by Walkley-Black wet oxidation method (Walkley and Black, 1934). The media was determined by using the CNS TruMac Determinators (LECO). This analysis was done at the beginning and after finish the experiment. Only one gram for each mixed growing media with different ratio was put into the combustion boat. All the sample materials in the combustion boat goes through an oxidative reduction process. It will undergo the oxidative reduction processes at 1350°C.

Plate 3.2 : CNS TruMac Determinators (LECO)

3.2.7 Cation Exchangeable Capacity (CEC) and Exchangeable Cations

The CEC and exchangeable cations (K^+, Ca^{2+}, Mg^{2+}, and Na^+) was determined using 1M NH_4OAc buffered at pH 7.0 as extractant by leaching method (Schollenberger and Dreibelbis, 1930). About 10g of media was weighed and placed inside the leaching tube. Then, 100ml of 1M NH_4OAc was poured thoroughly into the media and open slowly the tube valve for leaching. The leach was about 8 to 10 drops per minute and need to wait for 6 hours. After finish this step, the leachate solution was used to analyse the exchangeable cations (K^+, Ca^{2+}, Mg^{2+}, and Na^+). The Atomic Absorption Spectrophotometer (AAS) was used to read the K^+, Ca^{2+}, Mg^{2+}, and Na^+ concentrations. Then, the media was washed by 100ml of alcohol for twice in the leaching tube. After that, 100ml of 0.1N K_2SO_4 was poured onto the media and the leachate solution was used for determine the CEC by Atomic Absorption Spectrophotometer (AAS). Each the cycle or step required to wait about 6 hours before proceed to the next step.

Plate 3.3 : Atomic Absorption Spectrophotometer (AAS

3.2.8 Nutrient Content

The soil samples were digest by using Dry-ashing method (Lambert, 1976; Glooschenko, 1978; Munter et al., 1984; Papp and Harms, 1985) to determine the nutrient content in the media. About 1g of dried sample(media) was weighed and placed into a crucible. Then, the media sample was placed in a muffle furnace and ash at 550^{0}C for 6 hours. After that, the sample was evaporated to dryness using a hot plate in a fume chamber. A few drops of distilled water were added to the media followed by 2ml of concentrated HCI, and evaporated to dryness in a fume chamber. Then, 10.0ml of 20% HNO3 was added to the media and place in a water bath for 1 hour. The sample was filtered into 100ml volumetric flask by using filter paper. Macronutrient elements (P, K, Ca, and Mg), micronutrient elements (Fe, Na, Al, Ni, B, Cu, Mn, and Zn), and heavy metal (B, Cd, Cr, Cu, Mn, Ni, Pb, and Zn) was analyzed by Inductively coupled plasma optical emission spectroscopy (ICP-OES).

Plate 3.4 : Inductively coupled plasma optical emission spectroscopy (ICP-OES)

3.3 Preparation of Chilli Plant

3.3.1 Sowing and Transplant the Seedling

The planting material used in this study is *Capsicum annuum L. Var. Kulai*. The seed was 461 Sakata Hot Pepper F1 Hybrid from Pewaris Bumi Hijau Sdn. Bhd, Telok Panglima Garang, Selangor. *Capsicum annuum L. Var. Kulai* seeds were tested to determine the potential of the seeds to germinate and able to grow normally at the field. The seeds were placed on wet tissue paper inside the tray. Then, sufficient distilled water was applied and the tray was placed nearby to the light source and kept in room temperature. After 3 days, about 85% of the seeds in the tray germinated. *Capsicum annuum L. Var. Kulai* seeds were germinated in the 25 mm seed trays filled with peat soil as germinating medium. In each planting hole, the growth material held a single seed. Then, seeds were sprayed with tap water and the sowing was placed on the bench. The seeds were continuously sprayed with water twice per day until 21 days (3 weeks). After 21 days (3 weeks), only healthy seedlings were transplanted into polybags of size 40 cm × 40 cm which containing different ratio combinations of CDD, coconut ash and biochar.

3.3.2 Water and Fertilizer Application

Watering was done using fertigation system which timer was provided. Using fertigation system, fertilizer solution was dripped directly to root zones. The plant was irrigated by drip irrigation twice daily. Application of Cooper Formulation solution was applied to the plants twice per day at 8.00am in the morning and 5.00pm in the evening. The average amount of water per plant was varied according to the growth phase of plant. The Electrical Conductivity (EC) of nutrient solution in the tank were regularly monitored using a portable conductivity mater.

3.3.3 Weed, Pest and Disease Control

Weed is plants that grow in an undesirable place and become a threat to the chilli place. Weed control was done manually by hands. That is why weeding is needed to prevent unnecessary competition mainly water and nutrients between main plants and unwanted plants. Pest and disease are the major problem in the crop management that have to control in the properly. The pest infected the plants severely during the flowering stage which is 45 day after transplanting. The larvae and adult of thrips suck

3.4 Measurement of Vegetative Growth

Data collection of plant growth and production such as plant height, stem diameter, days of flowering, number and weight of harvested fruit, and total leaf area were recorded during the experiment.

3.4.1 Plant Height

The height of the plant was measured every 2 weeks after transplanting. Plant height was taken from media surface level until the first internode located at the top of plant shoots which was measured by a measuring tape. All data were recorded. The data of plant height was expressed in centimeter (cm).

3.4.2 Stem Diameter

The stem diameter of the plant was measured in 2 weeks interval after transplanting. Stem diameter was measured 5 cm above the ground level using Vernier calipers. The data of stem diameter was expressed in millimeter (mm).

3.4.3 Days of Flowering

The flowering stage is a crucial phase in the life cycle of flowering plants, marked by the transition from vegetative growth to reproductive development. During this stage, plants undergo significant physiological changes as they divert their energy and resources towards the production of flowers, which are essential for sexual reproduction. The initiation and maturation of flowers lead to the formation of fruits and seeds. Environmental factors such as light duration, intensity, and nutrient availability play key roles in influencing the timing and success of the flowering stage. Effective management during this period, including proper light cycles and nutrient supplementation, is essential for maximizing flower production and ultimately achieving successful reproduction in flowering plants. The data pertaining to the number of days to initiation of flowering, 50% of flowering, and initiation of fruit set. Days of flowering was recorded manually during starting flowering season of chilli (4WAT) until harvesting period.

3.4.4 Number and Weight of Fruit (Yield)

Mature fruits were harvested from three plants of each treatment combinations at fruit ripening stage of 120DAT. Total numbers of fruits were calculated and total fresh weight of fruit was weighed using an electronic balance immediately after harvest.

3.4.5 Total Leaf Area (TLA)

From each treatment combination, three plants were chosen, and each plant's entire leaf area was measured by carefully disassembling every leaf component.Total leaf area was measured with an automatic leaf area meter (Li-3000, Li-cor Inc., Lincoln, NE, USA). At the destructive stage, the total leaf area of each plant was measured and documented.

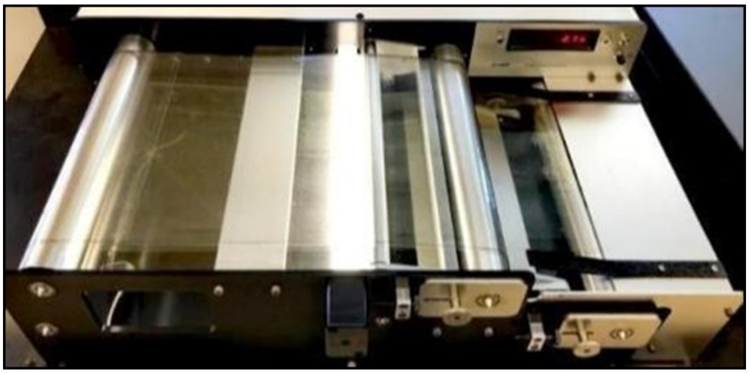


Figure 3.1 : Leaf Area Meter (Li-3000, Li-cor Inc.,Lincoln, NE, USA)

3.4.6 Relative Chlorophyll Content

Leaf chlorophyll concentration is an important parameter that is regularly measured as an indicator of chloroplast content, photosynthetic mechanism and of plant metabolism. Chlorophyll is an antioxidant compounds which are present and stored in the chloroplast of green leaf plants and mainly it is present in the green area of leaves, stems, flowers and roots (Mirza et al., 2013; Srichaikul et al., 2011). However, the chlorophyll production is mainly depended on penetration of sun light and it is the main source of energy for plant (Srichaikul et al., 2011). Leaf chlorophyll concentration is an important parameter that is frequently measured as an indicator of chloroplast development, photosynthetic capacity, leaf nitrogen content, or general plant health. The chlorophyll content was determined by Markwell et al. (1995) method. The SPAD 502 Plus Chlorophyll Meter was used to measure the chlorophyll content or “greenness” of the plants by simply clamp the meter over leafy tissue, and receive an indexed chlorophyll content reading (-9.9 to 199.9) in less than 2 seconds. The analysis was conducted during 12WAT in a morning day

Figure 3.2 : SPAD 502 Plus Chlorophyll Meter

3.5 Root Size and Distribution

3.5.1 Root Length, Root Diameter, Root Surface Area and Root Volume

Three plants were selected from each treatment combinations and the root system were separated from the plant at 100DAT and was washed gently with running water to separate the root from the growing media. The roots were thoroughly cleaned by repeatedly dipping and rising in clear water. To determine the root morphological parameters, roots were put into acrylic trays on the root image analyzer (WinRhizo STD 1600+ Scanner, Regent Instruments Inc., Quebec, Canada) and rearranged to reduce root overlapping and crossing to get a clear scan image of the root. The scans of the root samples were analyzed by the software and the data of root length, root diameter, root surface area, and root volume were obtained.

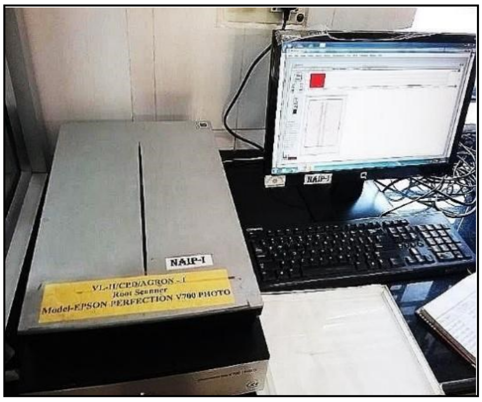


Figure 3.3 : Root Scanner WinRhizo

3.6 Dry Matter Production

3.6.1 Root Dry Weight, Shoot Dry Weight and Root to Shoot Ratio

Three plants which representing three replications of each treatment combinations were chosen and harvested at peak fruiting stage (100DAT). Plants were partitioned into leaves, stems and roots to determine the dry weights of individual plant part. Dry weight of the leaves, stem and roots were obtained by using an electrical weighing balance (TX3202L, Shimadzu Corporation) after oven drying the plant parts at 65°C for 72 hours. The total plant biomass was calculated from total dry weight of leaves, stem and root. The root: shoot ratio was calculated based on dry weights of shoot and root parts according to the equation by Hunt (1978) as stated below:

$$\text{Root: Shoot Ratio} = \frac{\text{Total Root Dry Weight}}{\text{Total Leaf \& Stem Dry Weight}}$$

3.7 Determination of Fruit Nutrient Content

The chilli fruit was collected during first harvesting period (16 weeks after transplant). The fresh weight of the fruit was recorded before it was put in the oven to dry at 60°C for 72 hours. Then, dried fruit sample were ground for the analysis using a mini grinder into medium size. The plant tissue sample was digest by using Dry-ashing method (Lambert, 1976; Glooschenko, 1978; Munter et al., 1984; Papp and Harms, 1985) to determine the nutrient content in the fruit. About 1.0g of dried sample(fruit) was weighed and placed into a crucible. Then, the sample was placed in a muffle furnace and ash at 550^{0}C for 6 hours. After that, the sample was evaporated to dryness using a hot plate in a fume chamber. A few drops of distilled water were added to the sample followed by 2ml of concentrated HCl, and evaporated to dryness in a fume chamber. Then, 10 ml of 20% HNO3 was added to the sample and place in a water bath for 1 hour. The sample was filtered into 100ml volumetric flask by using filter paper. Macronutrient elements (P, K, Ca, and Mg), micronutrient elements (Fe, Na, Al, Mn, and Zn), and heavy metal were analyzed by Inductively coupled plasma optical emission spectroscopy (ICP-OES). The total organic carbon, nitrogen and sulfur were determined by Walkley-Black wet oxidation method (Schumacher, 2002). The media was determined by using the CNS TruMac Determinators (LECO). This analysis was done after finish the experiment. Only one gram of sample was put into the combustion boat. All the sample materials in the combustion boat goes through an oxidative reduction process. It will undergo the oxidative reduction processes at 1350°C.

Plate 3.5 : Furnace

3.8 Data Analysis

All the data collected during the study were recorded and analyses using analysis of variance (ANOVA) by Statistical Analysis System (SAS 9.4). Differences between means separated using Tukey's Studentized Range (HSD) at P<0.05 level.

CHAPTER 4

THE PHYSICO-CHEMICAL PROPERTIES IN DIFFERENT GROWTH MEDIA MIXTURE OF COCONUT COIR-DUST, COCONUT ASH, AND PALM KERNEL BIOCHAR

4.1 Introduction

Globally, 998 million tonnes of agricultural waste are produced per year and in Malaysia, 1.2 million tonnes of agricultural waste are disposed of into landfills annually (Agamuthu, 2009). Even though agro-based industry generates various types of waste, these wastes has high potential to be converted into value added products (Samuelson et al., 2009). The objectives of this research were to determine the physio-chemical properties in different growth media mixtures derived from coconut and oil palm agricultural residues. Coconut coir-dust, coconut shell ash, and palm kernel shell biochar derived from coconut and oil palm agricultural residues have been selected as the basic materials in this study. This analysis was started on 1st February 2020. The study was involving the preparation of the soilless media, laboratory experiment, data collection and analysis. This analysis was done at the beginning of the experiment.

4.2 Materials and Method

4.2.1 Selection of Raw Material and Experimental Sites

The samples of this experiment were consisting of coconut coir dust (CCD) or cocopeat, coconut shell ash (CSA), and palm kernel shell biochar (PKSB). The CCD and chilli seed (planting material) were collected from Bumi Hijau (M)

Sdn.Bhd, Teluk Panglima Garang, Selangor. Meanwhile, coconut ash and PKS biochar were supplied by KY Global Sdn. Bhd. The preparation of agro-wasted media was conducted at Agrotechnology farm, Taman Pertanian Putra, UPM. Meanwhile, the chemical and physical analysis were conducted at Analytical Laboratory and Soil Physic Laboratory, Faculty of Agriculture UPM.

4.2.2 Preparation of Soilless Growth Media

The preparation of soilless growth media as shown in Table 3.1 using the method mentioned in section 3.1.1. There are 9 different mixture of growth media were prepared by volume from the basic materials such as T1(100%CCD), T2(100%CSA), T3(100%PKSB), T4(3CCD:1CSA), T5(2CCD:1CSA), T6(1CCD: 1CSA), T7(3CCD:1PKSB:), T8(2CCD: 1PKSB), T9(1CCD:1PKSB) respectively

4.2.3 Determine the Physical Properties

Analysis of pre soil samples was carried out for physical properties such as particle size, water and nutrient retention, bulk density, particle density, and porosity), and chemical properties (pH, electrical conductivity, organic carbon, total nitrogen, total phosphorus, cations exchange capacity, exchangeable cations, and nutrient content on sample).

4.2.3.1 Particle Size

Particle size was determined using the method mentioned in section 3.2.1.

4.2.3.2 Bulk Density, Particle Density, Porosity

Bulk density, particle density, and porosity were determined using the method mentioned in section 3.2.2.

4.2.3.3 Water Retention

The water retention was determined using the method mentioned in section 3.2.3.

4.2.4 Determine the Chemical Properties

Analysis of pre soil samples was carried out for chemical properties such as pH, electrical conductivity, organic carbon, total nitrogen, total phosphorus, cations exchange capacity, exchangeable cations, and nutrient content on sample.

4.2.4.1 pH and ELECTRICAL CONDUCTIVITY

The soil pH and electrical conductivity were measured using the method mentioned in section 3.2.5.

4.2.4.2 Total Organic Carbon, Nitrogen, and Sulfur

The total organic carbon, nitrogen and sulfur were determined by using the CNS TruMac Determinators (LECO) as mention in section 3.2.6.

4.2.4.3 Cation Exchangeable Capacity (CEC) and Exchangeable Cations

The CEC and exchangeable cations (K^+, Ca^{2+}, Mg^{2+}, and Na^+) was determined using 1M NH_4OAc buffered at pH 7.0 as extractant by using leaching method as mentioned in section 3.2.7.

4.2.4.4 Nutrient Content

The procedure of Dry-ashing method was explained in section 3.2.8.

4.2.4.5 Nutrient retention

The nutrient retention was determined by incubation method as referred in section 3.2.4.

4.3 Statistical Analysis

All the data collected during the study were recorded and analysed using analysis of variance (ANOVA) by Statistical Analysis System (SAS 9.4) for complete randomized design (CRD) with three replications to determine the significance difference between the growth media means. Differences between means separated using Tukey's Studentized Range (HSD) at $P \leq 0.05$ level.

4.4 Results and Discussion

4.4.1 Physical Properties Analysis

4.4.1.1 Particle Size

The particle size is important because the amount of open space between the particles influences how easily water moves through a soil and how much water the soil will hold. Particle-size distributions are used to estimate soil properties such as soil moisture characteristics and hydraulic conductivity (Bittelli et al., 1999; Khodaverdiloo et al., 2011), thus accurate estimation of soil properties strongly depends on the accuracy of particle size determination. The physical and chemical behaviors of soils are significantly influenced by particle-size distribution which is important for soil interpretations, determination of soil hydrologic qualities, plant nutrient requirements and classifications (Eshel et al., 2004). The particle size of each material can be known by refer to the Table 4.1. Coconut shell ash can be classified as the very coarse particle size because it contained range about 600μm to 4.75mm diameter. Meanwhile, CCD was contained the medium particle size range about 500μm to 2mm diameter, followed by the PKS biochar as the finest material that contained about 300μm to 600μm diameter of particle size range. Jaguaribe (2005) also conducted the experiment about influence of coconut shell activated carbon particle dimensions on aqueous phase adsorption by classified to particle size range of 1.0 mm to 2.36mm. Fornes (2003) reported that more than 90% of the CCD or cocopeat particles were from pith tissues which were less than 8 mm. A similar resultwas obtained by Noguera et al. (2003) with 90% of coconut coir dust particles were less than 8 mm. Nasrul

(2014) demonstrated the experiment related characterization of bio- oil from palm kernel shell pyrolysis. From the research, the palm kernel shell collected had standard particle sizes range of 212μm to 300 μm, 300μm to 600 μm, 600μm to 1.18 mm and 1.18mm to 2.36 mm in diameter. Abbas (2019) were studies the effect of PKS size on the biochar size and the filled vulcanizate. The selected PKSsize of 300μm, 250μm and 100μm were pyrolyzed at 500°C for six hours. Fine particlesize is results in better reinforcement. However, growth media with particles well distributed or combined into many size classes. The smaller particles may move into the spaces among the larger particles. As a consequence, the total porosity and the aeration space of the growth media will be reduced (Spomer,1979). On the other hand,the volume of water held by the substrate may increase as a result of the increment ofthe number of small pores (Ansorena, 1994).

Table 4.1 : The particle size of the materials

Material	Particle size
Coconut coir dust	500μm - 2mm
Coconut shell ash	600μm - 4.75mm
PKS biochar	300μm - 600μm

4.4.1.2 Bulk Density, Particle Density and Porosity

Bulk density is soil mass divided by unit volume, meanwhile the particle density represents the average density of all the minerals composing the soil. Porosity is that portion of the soil volume occupied by pore spaces (Thien and Graveel, 2003). The bulk density (Appendix G-c), particle density (Appendix G-d) and porosity (Appendix G-e) were significantly ($P \leq 0.05$) affected by different growth media. According to Figure 4.1, T3 was recorded the maximum value of bulk density and particle density of 0.88g/cm^3 and 1.07g/cm^3, followed by T2 demonstrated as the second maximum value of bulk density and particle density of 0.79g/cm^3 and 1.04g/cm^3. Meanwhile, T1 was revealed the minimum value and below the optimum range of bulk density (0.08g/cm^3) and particle density (0.12g/cm^3), thus it has the higher porosity about 32.0% than porosity in T2 (24.3%) and T3 (17.7%) as illustrated in Figure 4.2. According to Abad et al. (2005) and Asiah et al. (2004), the normal range of bulk density and particle density in soilless media are 0.25 g/cm^3 to 0.75g/cm^3, and 0.26 g/cm^3 to 1.07g/cm^3.

Meanwhile, the optimum range of porosity is between 5% to 30%. Thus, the optimum range of bulk density, particle density and porosity in growth media had proper conditions and caused better support of water and nutrient elements for plant leading to good growth (Olympious,1992; Kumar and Goh, 1999). Sarkar et al.(2021) proved that CCD contained the high porosity of 22.63%. In contrast, T3 also demonstrated as the lowest amount of porosity compared to the other growth media as shown in Figure 4.2. George (2013) proved that CCD contained low bulk density and particle density, but high in porosity. Krishnapillai et al. (2020) also studied that CCD contained low bulk density (0.18 g/cm^3) and particle density (0.8 g/cm^3) and high cation exchange capacity. Thien and Graveel (2003) stated that the relationship of bulk density and particle density with porosity is reciprocal. It is because bulk density and particle density typically increases as the ratio of solids in a soil increases, and conversely decreases as the ratio of solids decreases. Bulk density considers both the solids and the pore space, whereas particle density considers only the mineral solids.

Particle density are used with bulk density to calculate the pore space (porosity) occupied by air and water in growth media. Table 4.1 also shown that increase rate of CSA and PKSB resultant in increase of bulk density and particle density in growth media. Fernandes and Corá (2004) found that increasing the bulk density value have decreased the total porosity and aeration space, and increased buffering water and remaining water. These finding associated with the increase of the growth media mass that have occupied part of the pore space that was filled out with air, changing the pore size distribution. The particles occupied the air space because of the increase of the substrate mass and being the cause of the reduction of the total porosity, and the pore size distribution changed. Probably, the small particles have occupied the void space among the large particles, transforming large pores into small ones, which increased the water hold capacity of the growth media (Spomer, 1979; Ansorena, 1994). Moreover, mixing and transportation of low bulk density media are much easier than those of high bulk density.

However, media with a low bulk density not provide adequate support for the plant and the plant may be heavy at the top reported by Nagaraj et al. (2018). Raviv and Lieth (2008) also reported that an increase in bulk density is associated with decrease in total pore space and thus affects growth mainly through the effects of reduced free pore space. A decrease in total pore space will often decrease oxygen transport and decrease root penetration. A decrease in total pore space may also increase the water retention as pore diameters decrease, which is to say that loss of physical structure often results in an increase in water retention of the remaining material. The texture and structure, the level of induced compaction are the main properties governing amount and type of pore space in the soil. Organic matter affects porosity through its enhancement of soil aggregation.

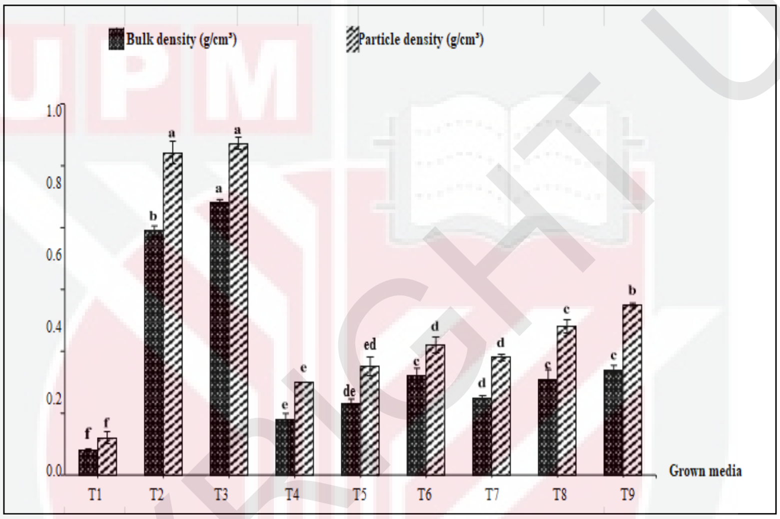


Figure 4.1 : The bulk density and particle density on different growth media

Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB.

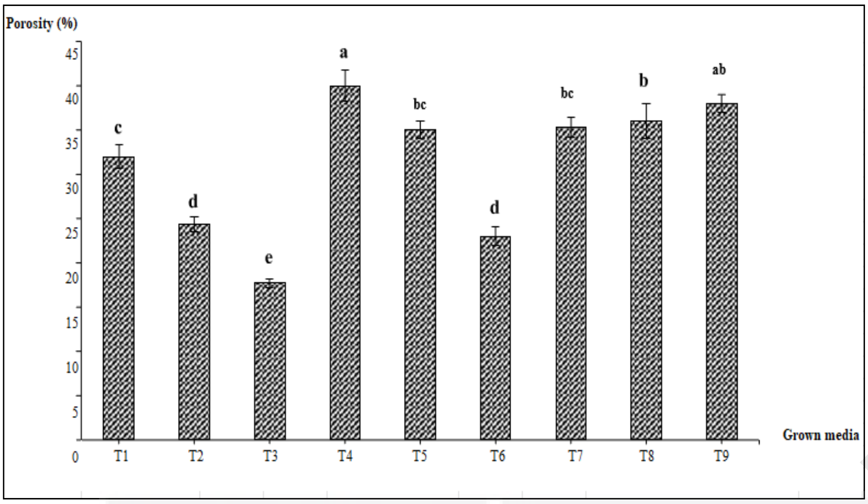


Figure 4.2 : The percentage of porosity on different growth media
Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB.

4.4.1.3 Water Retention

Water holding capacity or water retention is heavily affected by soil organic matter and texture and had significant influence for varied application such as regulating plant growth, soil drainage and soil functional attributes (Bordoloi et al.,2019). The pressure potential (in kPa) was representing the crop stress level on soil or media. Appendix G-f reveal that the water retention across the pressure potential were significantly (P≤0.05) affected by different growth media. Water retention of all growth media shown the significant (P≤0.05) decreased across the pressure potential as refer to Figure 4.3. According to Figure 4.3, T1 possessed the highest water retention range of 94% on - 1kPa that is nearly twice times more than water retention of T2(51%) and T3(56%) which due to increased porosity of water hyacinth and high proportion of micropores (indicated by high volumetric water content at -1.0 kPa suction) reported by Awang (2009). Meanwhile, growth media T5 demonstrated as the second highest water retention of 87% on pressure potential -1 kPa followed by growth media T7 (85%). According to Abad et al. (2005) and Asiah et al. (2004), the optimum range of water retention in soilless media is 20% to 60%. Thus, all growth media are demonstrated contain the optimum range except growth media T1, T4, T5, and T7 were exceed the normal range of water retention in soilless media. These finding proved that the increased rate of CCD have increased the water retention in growth media as refer to line graph in Figure 4.3. According to Yang et al. (2014), organic matter affects water retention at higher matric potentials by altering structural parameters, meanwhile organic matter functions by increasing soil adsorbing capacity to retain more water at lower matric potentials. Yang et al. (2014) also found that correlation coefficients between bulk density and organic water contents decreased as matric potential decreased, and thus became a poorer predictor of soil water retention. Sarkar et al. (2021) also found that CCD contained the highest water holding capacity at 89.50%. The increase of CCD in the mixture increased the water holding capacity because it acts as an absorbent that can hold a large volume of water. Thus, the CCD based media acted as an absorbent that held significantly more moisture in comparison to other growth media. The hygroscopic properties of CCD make it a good water absorbent material that is very effective in increasing the water-holding capacity of a soil in dry periods (Liyanage et al., 1993; Sherin et al., 2004; Subramanian et al., 2006). Moreover, bulk density and particle size have a close correlation with total porosity and water retention (Wösten et al., 2001; Ruehlmann and Körschens, 2009). Londra et al. (2018) stated that CCD is composed of spongy parenchyma cells and will hold up to 80 percent water once the excess drains away. Krishnapillai et al. (2020) also studied that CCD contained high moisture retention capacity, low bulk density (0.18 g/cm$^{3)}$ and particle density (0.8 g/cm^3) and high cation exchange capacity. These characteristics also make CCD ideal for use as a mulch and soil amendment (especially for dry and sandy areas with low water retention). The finding also is indicative of the ease of the uptake of water and nutrition by plants as well as the wetness in various growing systems. Growth is highest at low water retention forces, but very low water retention forces are sometimes avoided, for example, when the amounts of air-filled pores become too low for proper oxygen transport. The air content recommendations for optimal growth are found by Kipp et al. (2001).

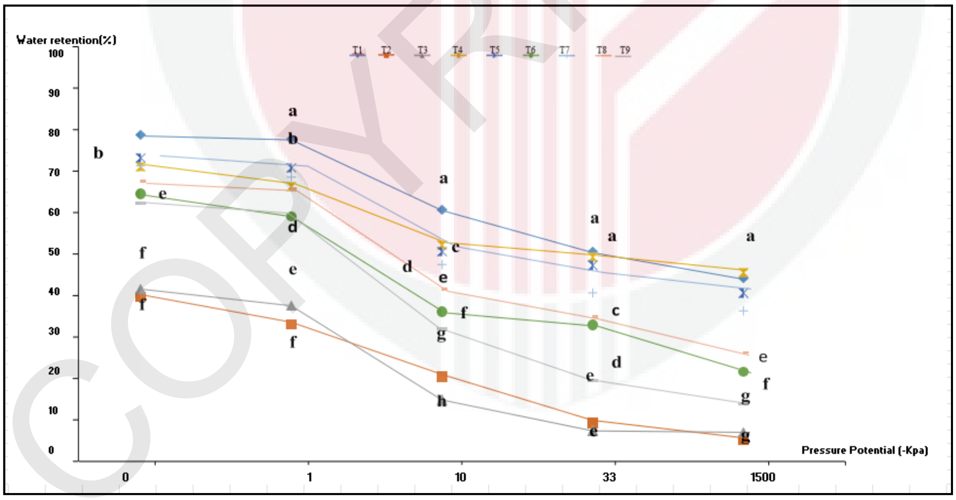


Figure 4.3 : The interaction between different growth media and pressure potential on water retention. Within the pressure potential, means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

4.4.2 Chemical Properties Analysis

4.4.2.1 pH Value

A knowledge of the soil and the crop is important in managing soil pH for the best crop performance. For most plants, the optimum pH range is from 5.5 to 7.0, but some plants will grow in more acid soil or may require a more alkaline level. Plant nutrients leach from the soil much faster at pH values below 5.5 than from soilswithin the 5.5 to 7.0 range. In some mineral soil aluminum can be dissolved at pH levels below 5.0 becoming toxic to plant growth. Soil pH may also affect theavailability of plant nutrients. The pH value was significantly ($P \leq 0.05$) affected by different growth media (Appendix G-a). Figure 4.4 show the pH value range on different growth media between 4.55 to 7.89. From the Figure 4.4, T2 reached thehighest pH value 7.89 and leave the T3 as the second higher of pH value 6.63, meanwhile T1 has the lowest pH value 4.55 compare with other growth media. Moreover, T4 to T8 exhibited the optimum pH range between 6.29 to 5.63.

According to Piash (2016), coconut shell ash and PKS biochar found to be alkaline in nature due to high dissolution of base cations. The burnt or charred plant residues contain a larger amount of alkalinity due to the volatilization of organic constituents under thermal conditions leading to the concentration of alkaline constituents (Neina,2019). Cheah (2014) proved that coconut shell ash and biochar alkalinity can be attributed to four broad categories: surface organic functional groups, carbonates, soluble organic compounds and other inorganic alkalis including oxides, hydroxides, sulfates, sulfides, and orthophosphates. Piash (2016) also stated that increased pH of coconut ash and biochar amended acid soils may help to reduce Al toxicity, increase P availability and liming agent. Njoku and Mbah (2012) also reported that organic amendment can stabilizes soil pH by acting as buffering agent against undesirable pH fluctuations in soil. However, the higher pH than recommended for plant growth in soilless media of 5.0 to 6.5 can have a negative effect on plant growth (Bunt,2012). Meanwhile, Yahya (2009) proved that the pH of 100% cocopeat and 70 cocopeat: 30 kenaf core fiber were higher about 6.6 of pH value than those of the other media. Thus, cocopeat need to do some liming for reach the suitable pH for plant.

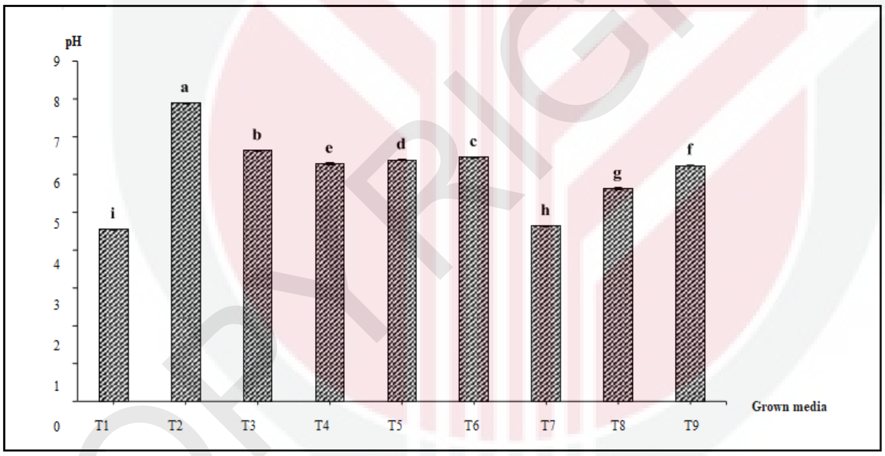


Figure 4.4 : The pH value on different growth media. Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

4.4.2.2 Electrical Conductivity

Electrical conductivity is a measure of the salinity (total salt level) of an aqueous solution. Electrical Conductivity showed significant (P≤0.05) differences between growth media (Appendix G-b). Figure 4.5 shown that the electrical conductivity on different growth media. T2 contained the highest EC value 2.7 dS/m followed by T6 with EC value of 1.7 dS/m, meanwhile T7 indicate as growth media that contained the lowest EC value of 0.29 dS/m. Yahya (2009) reported that the acceptable range of initial EC of a good soilless media should be between 0.4 to 1.5 dS/m. According to Horneck (2007), EC values reflect the total inorganic ion concentration in the media extracts. Higher EC of T2 reflects that coconut ash contains relatively high concentration of soluble salts which could be beneficial for plant growth. Yahya (2009) also stated that a low EC value indicates that the media did not contain excessive salt that could cause salinity injury to the plants. However, at the same growth media with low EC value contains insufficient amount of nutrients to support plant growth.

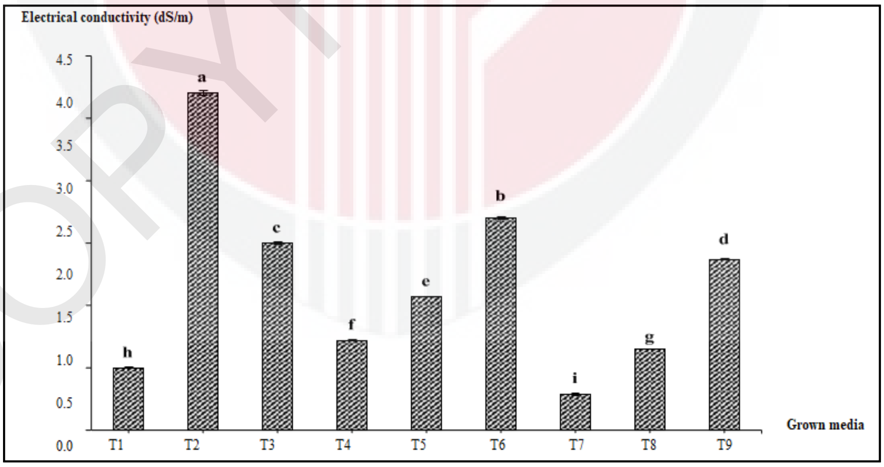


Figure 4.5 : The electrical conductivity on different growth media. Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

4.4.2.3 Cation-Exchange Capacity and Exchangeable Cation K,Ca,Mg,Na

Cation exchange capacity (CEC) is a measure of the soil's ability to hold positively charged ions. It is a very important soil property influencing soil structure stability, nutrient availability, soil pH and the soil's reaction to fertilizers and other ameliorants (Hazleton and Murphy,2007). In this experiment, the exchangeable cations (K^+, Ca^{2+}, Mg^{2+} and Na^+) and CEC was determined using 1M NH4OAc buffered at pH 7.0 as extractant. According to Appendix G-g and Appendix G-h, the exchangeable cations (K^+, Ca^{2+}, Mg^{2+} and Na^+) and CEC were significantly ($P \leq 0.05$) affected by different growth media. Figure 4.6 demonstrated the cation-exchange capacity on different growth media (T1 to T9). T2 contained highest CEC level of 12.57cmolc/kg, followed by T1 as the second highest CEC value of 10.86cmolc/kg. Meanwhile, Figure 4.7 shown the exchangeable cations K, Ca, Mg and Na on different growth media. The main ions associated with CEC in soils are the exchangeable cations potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), and sodium (Na^+) generally referred to as base cations (Rayment and Higginson, 1992). T2 contained highest CEC level of 12.57cmolc/kg with high of exchangeable K^+(3.07cmolc/kg) and exchangeable Mg^{2+} (0.52 cmolc/kg) compared to other growth media. Angalaeeswari and Kamaludeen (2017) found that the coconut shell ash (biochar) resultant in high cation exchange capacity (11.93cmolc/kg) due to contained high negatively charged and presence of high number of functional groups. Ogeleka (2017) reported coconut ash contained high in exchangeable cations K and Mg. Krishnapillai et al. (2020) studied that CCD contained high moisture retention capacity, high potassium content, low bulk density (0.18 g/cm^3) and particle density (0.8 g/cm^3) and high cation exchange capacity enabling it to retain high amounts of exchangeable potassium (K), sodium (Na), calcium (Ca), and magnesium (Mg).

George (2013) found that CCD has high cation exchange capacity (CEC) which enables it to retain large amounts of nitrogen and the absorption complex has high content of exchangeable K, Na, Ca and Mg. Nakhli (2017) stated that growth media considerably according to the nature of the cation used, concentration of salt applied and the equilibrium pH level with optimum CEC values are able to retain cationic fertilizers (K^+ and $NH4^+$) and prevent nutrient leaching. Meanwhile, Scott (2006) and Orji (2012) reported that the low level of exchangeable bases and lower pH in the media is an indication of heavy leaching of soil basic nutrients. Figure 4.6 and Figure 4.7 also demonstrated that T9 contained a lowest CEC (3.34cmolc/kg) with low of exchangeable cations K(0.86cmolc/kg), Mg(0.29cmolc/kg), and Na (0.022cmolc/kg. However, exchangeable Ca was highest in T9 with (2.96 cmolc/kg) compared to other growth media as refer in Figure 4.7. Growth media T2 and T1 have the large quantities of negatively charged sites on the surfaces which adsorb and hold positively charged ions (cations) by electrostatic force, whereas T9 only has a few quantities of negatively charged sites on the surfaces (Ogeleka et al.,2017). According to Sumner and Davidtz (1965) and Arnold (1977), the amount of CEC measured varied

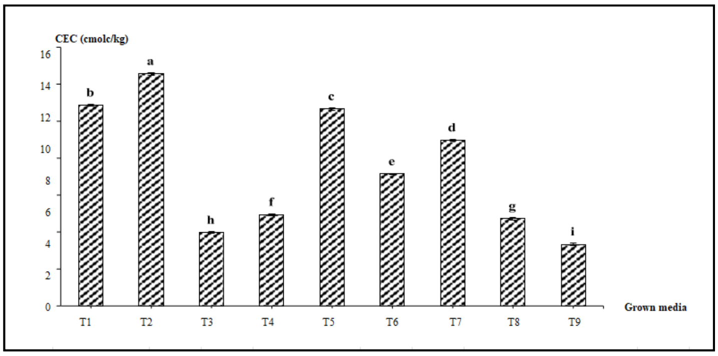


Figure 4.6 : The cation-exchange capacity on different growth media. Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

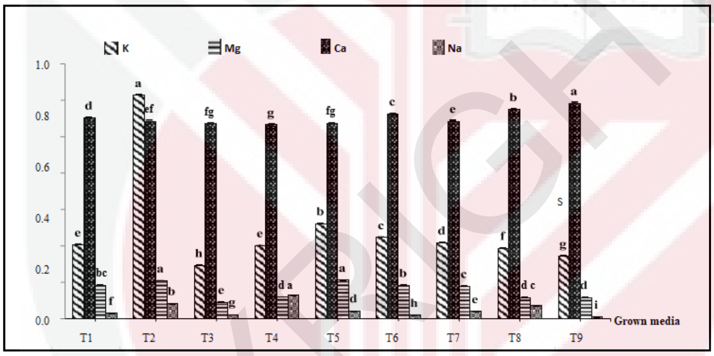


Figure 4.7 : The exchangeable cations K, Ca, Mg, and Na on different growth media. Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

4.4.2.4 Nutrient Content

According to Appendix G-j to Appendix G-l, the analysis of variance of macronutrient (include nutrient gaseous elements), C/N ratio, micronutrients element, and heavy metal showed significant (P≤0.05) differences between growth media. However, only Cd content is not significant differences between growth media. Table 4.2 shown the chemical composition on nine different growth media (T1 to T9). This chemical composition can compare by three categories such as macronutrient, micronutrients element, and heavy metal. Macronutrients are nutrients that are required in larger amounts by plants such as C, H, N, O, P, K, Ca, S, and Mg (Hu et al.,2001). Table 4.2 shown that T2 was mostly contained the maximum amount of macronutrient elements of N(0.58%), S(0.15%), P(13.90mg/l), Ca(62.4mg/l), K(191.70mg/l), Mg(36.67mg/l), followed by T3 that contained the highest level of C element of 73.96% and C/N ratio (232.33) but contained the low amount of S (0.079%) compared to other growth media. Micronutrients are elements required in smaller quantities by plant such as Fe, Na, Al, Ni, B, Cl, Cu, Mn, Mo, and Zn (Römheld *et.al*,1991). Table 4.2 illustrated that T2 also revealed as the maximum level of micronutrient elements of Al(101.20mg/l), Cu(0.54mg/l), Fe(71.10mg/l), Mn(3.30mg/l), Zn(7.63mg/l) but not contained with element boron, followed by T3 was contained the highest concentration of micronutrient elements Ni(2.56mg/l) as well as lowest in B(0.033mg/l), Na(8.56mg/l) compared with other growth media. Heavy metal includes both essential and non- essential trace metals, which may be toxic to the plant depending on their own properties, availability (chemical speciation), and concentration levelsHeavy metals such as B, Cd, Cr, Cu, Mn, Ni, Pb, and Zn are toxic or poisonous although in a low concentration.

By referred to Table 4.2, mostly the heavy metal was highest in T2 although it contained very high of macro and micronutrients. T2 contained the highest concentration of heavy metal of Cd(0.03mg/l), Cr(1.42mg/l), Cu(0.54mg/l), Mn(3.30mg/l), Pb(0.81mg/l), Zn(7.63mg/l) except for elements B and Ni.

Furthermore, T1 was contained the highest of B (0.35 mg/l) content but lowest concentration of heavy metal Mn (0.13mg/l), followed by T3 has lowest concentration of B(0.033mg/l) and Cr(0.074mg/l). Meanwhile, T7 indicated the least concentration of Pb(0.012mg/l) compared to other growth media. By referred to Table 4.2, indicated increases of related macronutrients, micronutrients, and heavy metals content. Bonneau (2010) reported that coconut ash was found to contain a large amount of K (26%), P (0.89%), Ca (1.34%), Mg (4.58%), Na (4.11%), S (0.56%), Fe (1.64%). Similar result found by Baon (2009) where Plant Derived Ash (PDAsh) contained high of K (40%), Mg (13%), S (7%), and Ca (7%) contents. The high nutrient content of K (45.01%), P(4.64%) Na(15.42%), Ca (6.26%), Mg(1.32%) found in coconut shell ash (Amu et al.,2011). Chemical composition of coconut shell ash consist of Al (24.12%), Fe (15.48%), Ca (4.98%), Mg(1.89%), Na (0.95%),K (0.83%), Mn (0.81%), S(0.71%), and P (0.32%) reported by Bhartiya and Dubey (2018). Isah (2014) also found that oxides composition of coconut shell ash contained high Al (14.60%), Fe (12.40%), Ca (4.57%), Mg(14.20%), Mn(0.22%), Na(0.45%), K(0.52%), and Zn(0.3%). Meanwhile, Ti content in coconut shell ash is 0.32% (Satheesh et al.,2019). Moreover, Hanudin et al.(2021) also found that 1.85% of K-total content, 1.02% of Ca-total content, and 0.51% of Mg-total content in coconut ash. Coconut shell ash contained Al (5.45%), Ca(0.57%), Fe (12.4%), K (0.52%), Mg (16.2%), and Na (0.45%) reported by Debnath et al.(2013).

Iqbaldin et al.(2013) found that coconut shell carbon (CSC) have similar results with coconut shell ash in Table 4.2, where contained the high total C

(64.87%), total N (0.84%), and total S (0.09%). High organic C (14.33g/kg), N (0.73g/kg), P (1.72g/kg) also found in 6-weeks incubations of 10t/ha coconut ash (Awotoye et al.,2014). Moreover, Awotoye (2014) also reported the nutrient status of coconut ash was higher when compared with the unashed counterpart, however it also contained with high concentration of heavy metal that can cause toxic effects on a wide diversity of organisms (Marcovecchio et al.,2007). According to Halmi and Simarani (2021), palm kernel shell biochar contained high content of total C (434.1 $g \cdot kg^{-1}$), total N (5.07 $g \cdot kg^{-1}$), total P (1.56 $g \cdot kg^{-1}$), and C:N (85.62). C/N ratio is one of the most important factors affecting composting process and compost quality reported by Golueke (1991). The C/N ratio is usually employed to indicate the maturity degree of compost Bernai et al. (1998). A decrease in C/N ratio implies an increase in the degree of humification of organic matter. Generally, composting was carried out under a wide range of initial C/N ratios from 11 to 105 depending on the raw materials Eiland et al. (2001); Ghosh et al. (2007).

Tripetchkul et al. (2012) and Loh et al. (2013) suggested that 20:1 C/N and 25:1 C/N formulation is the ideal ratio for high microbial activities occurred leading subsequently to rapid degradation of organic matters of the compost. The C/N ratio of biochar indirectly relates to N mineralisation or immobilisation during biochar-soil-microorganism's interactions in decomposing organic materials (Ameloot et al., 2015). Cayuela et al. (2014) stated that the C/N ratio is the main element to indicate the N_2O emission where high C/N ratio influences the reduction of soil N_2O emission (Brassard et al., 2016). Biochar with a low C/N ratio showed negative effects towards N_2O emissions compared to high C/N which can reduce N_2O emission of the soil (Ameloot et al., 2013). The C/N ratio of PKS biochars produced found by Haryati et al. (2018) were between 110 to 332 which indicates that N_2O emissions from PKS amended soil are low. Kalaivani, and Jawaharlal (2019) proved that cocopeat contained N (0.41%), P (0.81%), K (1.32%), Ca (0.21%), Mg (0.31%), Fe (23.0mg/l), and Zn (22.0mg/l). Wira et al.(2011) also found that cocopeat contained N (0.53mg/l), P (17.43mg/l), K (9.63mg/l), Ca (4.77mg/l), Mg (0.19 mg/l), Fe (0.15mg/l),Mn (0.02mg/l), Zn (0.05mg/l), Cu (0.03mg/l). Meanwhile, Spehia et al.(2019) stated that the low of Mn (0.32%) content found in cocopeat.

Table 4.2 : Chemical composition on different growth media by using AAS and ICP-OEs

Growth media	Carbon (%)	Nitrogen (%)	C:N ratio	Sulfur (%)	P(mg/L)
T1	43.33±0.002i	0.41±0.000e	105.32±0.004h	0.10±0.002c	2.85±0.000g
T2	59.48±0.000f	0.58±0.001a	102.09±0.14i	0.15±0.001a	13.90±0.002a
T3	73.96±0.004a	0.32±0.001g	232.33±0.83a	0.079±0.000e	4.22±0.000e
T4	50.59±0.010h	0.45±0.000d	113.79±0.031g	0.10±0.002c	4.59±0.001d
T5	57.47±0.011g	0.46±0.000c	125.56±0.025f	0.11±0.001b	5.15±0.003c
T6	63.97±0.008e	0.48± 0.002b	132.06±0.56e	0.10±0.000c	5.26±0.000b
T7	65.14±0.012d	0.30± 0.002h	220.97±1.52b	0.084±0.000e	2.05±0.003i
T8	66.05±0.006c	0.32± 0.002g	205.58±0.98d	0.090±0.001d	2.31±0.002h
T9	73.84±0.000b	0.35± 0.000f	214.35±0.044c	0.077±0.002e	3.29±0.001f
HSD (P<0.05)	306.42***	0.027***	9143.88***	0.0015***	38.76***

Table 4.2 : Continued

Growth media	K (mg/L)	Ca (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)
T1	149.60±0.011b	43.59±0.000b	0.002±0.001a	0.069±0.001i	0.29±0.002c
T2	191.70±0.010a	62.40±0.000a	0.003±0.001a	1.42±0.001a	0.54±0.002a
T3	62.88±0.006f	42.94±0.001c	0.002±0.001a	0.074±0.002g	0.34±0.001b
T4	96.68±0.002e	21.87±0.001h	0.003±0.002a	0.62±0.002b	0.27±0.000e
T5	116.70±0.012^{d}	24.81±0.002^{g}	0.001±0.000^{a}	0.23±0.001^{f}	0.28±0.002^{d}
T6	126.50±0.003c	26.45±0.003f	0.001±0.000a	0.38±0.000c	0.29±0.001d
T7	40.74±0.003i	17.21±0.000i	0.001±0.001a	0.21±0.003g	0.17±0.000g
T8	42.24±0.002h	28.07±0.003e	0.001±0.000a	0.26±0.000e	0.16±0.000g
T9	55.69±0.001g	28.37±0.002d	0.001±0.001a	0.35±0.002d	0.18±0.001f
HSD ($P<0.05$)	8256.36***	601.52***	0.0000017***	0.52***	0.040***

Growth media	Al (mg/L)	Fe (mg/L)	Mg (mg/L)	Mn (mg/L)
T1	4.14±0.001i	5.74±0.003i	11.95±0.006g	0.13±0.000i
T2	101.20±0.000a	71.10±0.004a	36.67±0.003a	3.30±0.002a
T3	13.54±0.000e	47.09±0.001c	17.66±0.002b	0.88±0.001b
T4	55.92±0.003d	30.58±0.000e	12.10±0.000f	0.51±0.000e
T5	65.63±0.002c	32.91±0.003d	12.48±0.003d	0.52±0.000d
T6	97.62±0.002b	64.97±0.002b	13.70±0.000c	0.63±0.002c
T7	4.93±0.003g	15.12±0.000h	9.23±0.003i	0.31±0.002h
T8	6.07±0.005f	22.95±0.002f	10.27±0.000h	0.38±0.003g
T9	4.31±0.000h	22.65±0.002g	12.23±0.000e	0.47±0.001f
HSD ($P<0.05$)	5104.59***	1470.13***	212.12***	2.78***

Table 4.2 : Continued

Growth media	B (mg/L)	Pb (mg/L)	Ti (mg/L)	Ni (mg/L)	Zn (mg/L)
T1	0.35±0.002a	0.03±0.000e	0.099±0.000h	0.31±0.000c	0.22±0.000g
T2	-	0.81±0.001a	0.54±0.001b	0.75±0.002b	7.63±0.001a
T3	0.033±0.001g	0.018±0.000f	0.25±0.004d	2.56±0.002a	0.57±0.000e
T4	0.039±0.001f	0.038±0.002d	0.61±0.000a	0.28±0.003d	0.69±0.002c
T5	0.12±0.002b	0.046±0.000c	0.60±0.002a	0.11±0.000h	0.66±0.000d
T6	0.097±0.003c	0.24±0.000b	0.50±0.003c	0.19±0.001e	1.37±0.002b
T7	0.071±0.001e	0.012±0.002g	0.11±0.000g	0.11±0.000h	0.24±0.003f
T8	0.084±0.002d	0.014±0.002g	0.23±0.001e	0.14±0.003g	0.22±0.001g
T9	0.072±0.000e	0.019±0.000f	0.14±0.000f	0.18±0.002f	0.20±0.000h
HSD (P<0.05)	0.031***	0.21***	0.14***	1.88***	17.26***
	HSD (P<0.05)	5104.59***	1470.13***	212.12***	2.78***

Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). * and *** significantly different at P≤0.05, and 0.001 respectively and NS= not significant. Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB.

4.4.2.5 Nutrient Retention

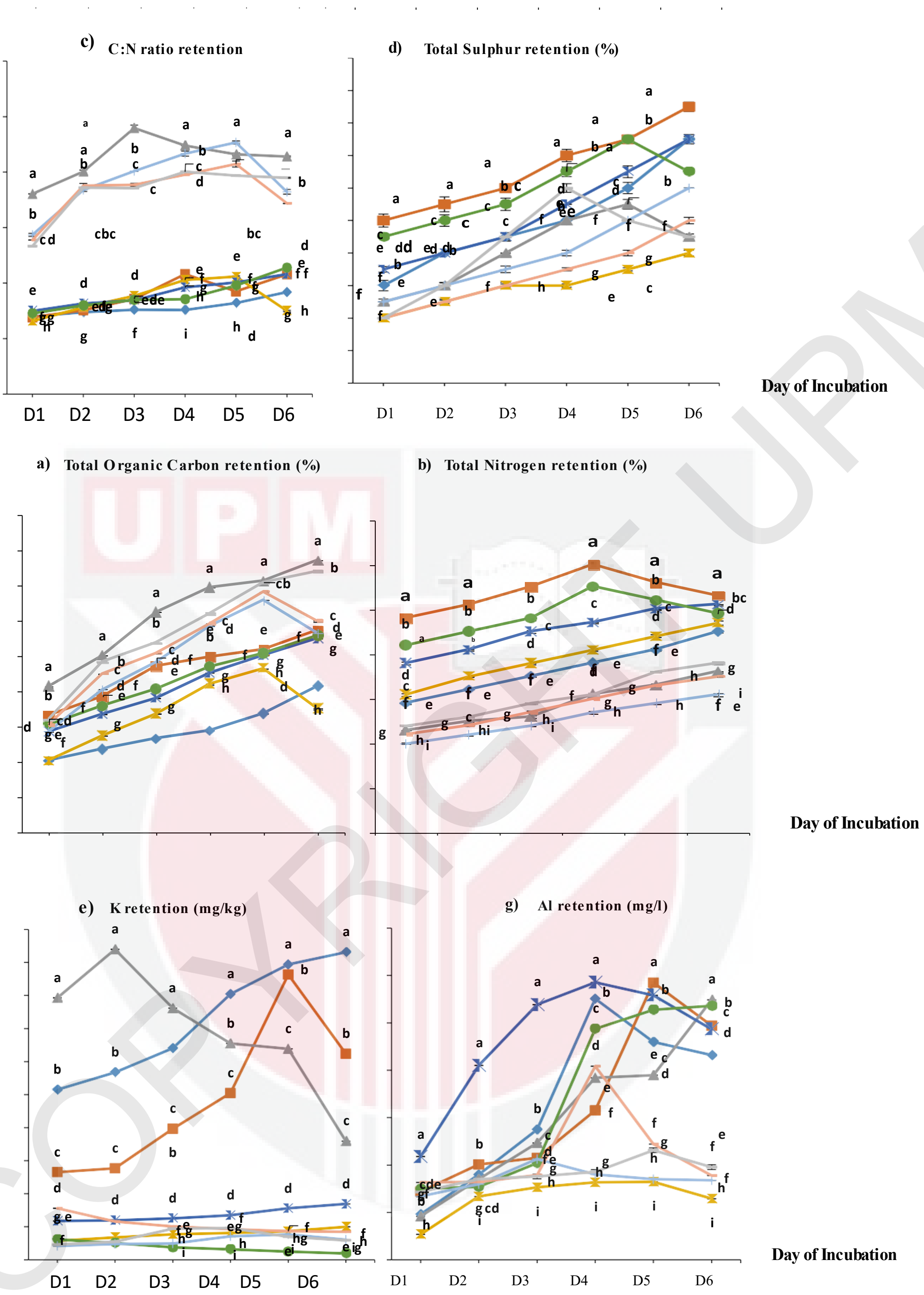
The analysis of variance of nutrient retentions of total organic C, total N, total S, C:N ratio, S, K, P, Al, Ca, Fe, Mg, Mn, Na, and Zn showed significant (P≤0.05) differences between growth media across the incubation days (Appendix G-m). Figure 4.8 shown the nutrient retention in different growth media across the incubation days from day 1 to day 15. Figure 4.8a shown the total organic carbon retention in all growth media were increased across the incubation days. However, total carbon retention T4, T7, and T8 were declined when reach 15 days. Meanwhile, all growth media shown the upward pattern in total nitrogen retention across incubation day, except total nitrogenretention dropped in T2 and T6 when reach the incubation days of 12 and 15 as illustrated in Figure 4.8b. According to the Figure 4.8c, C:N ratio in all growth mediawere increased across incubation days. In contras (t, C:N ratio in T3 was decreased from incubation 9 to day 15, followed by C:N ratio T2 and T9 when reached the incubation day 12 to day 15.

Meanwhile, C:N ratio in T4, T7, T8, and T9 were droppedat 15 day of incubation. According to Plaimart et al.,(2021) found that coconut ash (biochar) retarded nitrate leaching via slower nitrification in digestate-amended soil. Wang et al. (2015) found that nitrification was retarded by peanut shell biochar amendment in an acidic orchard soil. The utilization of biochar as a nitrification inhibitor could be a promising option for N-management in agriculture, which would be particularly relevant in co- application with a rich source of reduced nitrogen such as anaerobic digestate (Plaimart et al.,2021). All growth media shown the upward trend in total sulfur retention across the incubation days (Figure 4.8d). However, totalsulfur retention in T9 was declined at incubation day 12 and 15. The total sulfur retention in T3 and T6 dropped at 15 days of incubation. From Figure 4.8e indicated that K retention of all growth media shown the upward pattern along the incubation days from day 1 to day 12, but K retention in most of growth media were declined when reached the incubation day of 15 except for T3 and T6. Meanwhile, all growth media shown the increased pattern of P retention across the incubation days except P retention in T1 as refer to Figure 4.8f. The amounts of P retained can be increased when the contact time between growth media and the phosphorus supplied increases (Akinremi and Cho, 1991). However, Akhtar and Alam (2001) in their study showed that P availability in organic matter decreased for both organic and inorganic P sourceswhen increasing the time of incubation.

The amount of P decreased in incubated organic matter between one and six weeks (Al-Rohily et al., 2013). The decrease in the amounts of P can be generated by a P fixation in organic matter (Boukhalfa- Deraoui et al.,2015). According to Yu et al. (2013), P adsorption of the soil samples increased as the initial P concentration increased at lower P concentrations, and then increased to a lesser extent at higher P concentrations. In contrast, acids produced by the mineralization of fertilizers compete for adsorption with P, thereby reducing adsorption sites for P. Meanwhile, Novak et al.(2018) studied that P and K associated with the biochar are exposed to mineral weathering reactions at the surface and in pore spaces potentially resulting in their dissolution and release. The additional incubation time would influence P and K release equilibrium reactions because of exposure to other microbial (nutrient mineralization and assimilation) as well as other chemical mechanisms (precipitation and binding by organic ligands) that can counter the bioavailability. According to Figure 4.8g, Al retention in growth media T3, T6, and T8 were declined along the incubation days. Meanwhile, the Al retention in other organic matter were increased across the incubation days, but Al retention starting to decreased in T2, T7, and T9 when reached the 12 day and 15 day. All growth media were increased across the incubation days except Ca retention in T4, T5, T7, and T8 as presented in Figure 4.8h. The decreased trend of Fe retention was shown in all growth media when increased of incubation day (Figure 4.8i).

Figure 4.8 shown the Mg retention of all growth media indicated in upward trend across the incubation days. According to Figure 4.8k, the Mn retention shown the increased pattern in all growth media when increased the incubation days, except Mn retention in T1, T4, and T8. The Na retention shown the upward trend in all growth media when increased the incubation days, except Na retention in T8 as refer to Figure 4.8l. Meanwhile, Figure 4.8m illustrated the Zn retention in all growth media were rose across the incubation day, except Zn retention in T2, T3, T6 and T9. Nutrient retention capacity is of particular importance for the effectiveness of fertilizer applications and is therefore of special relevance for intermediate and high input level cropping conditions. Nutrient retention capacity refers to the capacity of the soil to retain added nutrients against losses caused by leaching. Plant nutrients are held in the soil on the exchange sites provided by organic matter (National Research Council,1993; Fischer et al.,2008). Lehmann and Joseph (2012) reported that the nutrient retention capacity attributed to the surface area, porosity, and a large range of pore distribution of organic matter particles.

The particle specific surface area (m^2/g) determines nutrient retention. The number of cations that hold nutrient anions in the organic matter increases with the surface area. Meanwhile, the decreased of nutrient retention in growth media was due to growth media reached the optimum nutrient concentration and loss strength to hold excess nutrient, thus nutrient volatilization and leaching occur along the incubation time (Ullah et al.,2017; Jordan and Herrera,1981; Eghball et al.,1997). According to Laird et al.(2010), nutrient leaching could diminish soil fertility, accelerate soil acidification, increase fertilizer costs for farmers, and reduce crop yields. Berek et al.(2018) reported that biochar has a great capacity to retain nutrients due to its numerous small pores and large surface area/charge. Highly weathered soils are poor in nutrients because of leaching. Biochar is believed to have high nutrient retention capacity. Such nutrient retention capacity is attributed to high surface area, porosity, and surface charge. For example, NH4-N adsorption is due to cation exchange on the surface functional (phenolic and carboxylic) groups of biochar and physical entrapment in biochar's porous structure. The application of biochar to soil could increase soil fertility and crop productivity by reducing leaching or even supplying nutrients (Glaser et al.,2002; Lehmann et al.,2003; Major et al.,2010). Moreover, biochar can play an important role in enhancing nutrient retention due to its surface charge density (Kongthod et al.,2015). Biochar mostly has negatively charged surfaces which increases the adsorption capacity of cation species (Lou et al., 2016). This can be partially attributed to effects on microbiology that reduce fertilizer losses via leaching (Atkinson et al., 2010; Tan et al., 2015).


c) C:N ratio retention
d) Total Sulphur retention (%)
D1 D2 D3 D4 D5 D6
Day of Incubation
a) Total Organic Carbon retention (%)
b) Total Nitrogen retention (%)
Day of Incubation
e) K retention (mg/kg)
g) Al retention (mg/l)
D1 D2 D3 D4 D5 D6
Day of Incubation

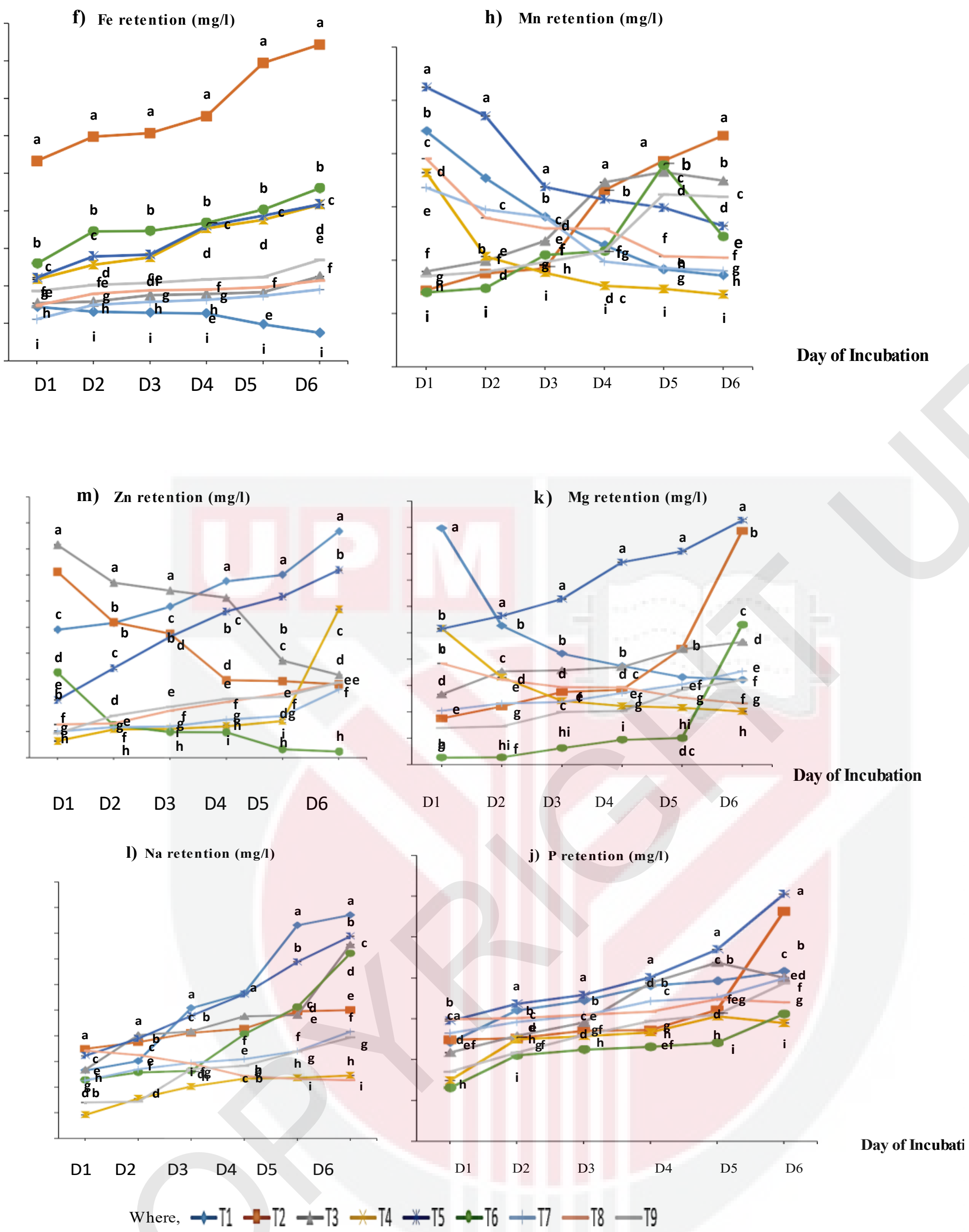


Figure 4.8 : The nutrient retention in different growth media across the incubation days from day 1 to day 15. Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

4.5 Conclusion

The comprehensive analysis of the experiment reveals that T2, consisting of 100% Coconut Shell Ash (CSA), emerged as the most favorable organic waste due to its high pH, electrical conductivity, cation-exchangeable capacity, exchangeable cations K and Mg, as well as elevated bulk density and particle density. It exhibits low porosity, indicating a reduced susceptibility to moisture loss. Coconut ash is rich in macronutrients, particularly N, P, K, and S, along with essential micronutrients, enhancing nutrient retention in growth media and potentially improving soil fertility for increased crop yields. Despite its benefits, the higher pH of coconut ash, surpassing the recommended range of 5.0 to 6.5 for soilless media, may negatively impact plant growth. Additionally, elevated heavy metal content in coconut shell ash poses a potential risk of toxicity to plants. Furthermore, coconut shell ash demonstrates lower water holding capacity compared to coconut coir dust (CCD) or cocopeat in this study. While previous research supports the positive impact of organic wastes on soil properties, including increased organic matter, nitrogen, pH, P, and cation exchange capacity, caution is warranted due to the potential drawbacks associated with coconut ash. Farmers are encouraged to explore organic farming practices using agro-wastes as soil amendments for their economic and eco-friendly benefits. However, to validate these findings, further studies should be conducted in field conditions, employing a fertigation system to assess the impact of different media on plant growth performance.

CHAPTER 5

EFFECT OF DIFFERENT GROWTH MEDIA MIXTURES ON GROWTH PERFORMANCE OF *Capsicum annuum* UNDER FERTIGATION SYSTEM

5.1 Introduction

his research was conducted in a field setting, specifically a shelter house, to assess the impact of varying growth media mixtures on the growth performance of *Capsicum annuum* under a fertigation system. The experiment involved the use of polybags sized 40 cm × 40 cm to accommodate the plants. The physio-chemical properties, as well as water and nutrient retention (as discussed in the preceding chapter), were analyzed. Chilli (*Capsicum annuum* Var Kulai) was selected as the chosen crop sample to examine the influence of different growth media mixtures on plant growth performance within a fertigation system. The fertigation system was established in January prior to the commencement of the experiment. A standardized rate of chemical liquid fertilizer (Cooper formulation) was applied through irrigation to provide essential nutrients for plant growth. Drip irrigation was employed twice daily to ensure proper hydration of the plants. The study encompassed the setup of the fertigation system, preparation of soilless media in polybags, field layout arrangement, sowing and transplanting of seedlings, weeding and insect control, data collection, harvesting, plant part destruction, and subsequent laboratory analysis.

5.2 Materials and Methods

5.2.1 Selection of Experimental Site, Planting Materials and Design

This study was conducted at Shelter House 3 at Agrotechnology Farm, University Agriculture Park, Universiti Putra Malaysia (UPM), Serdang, Selangor. The roof of shelter house was covered by using 0.04mm silver shine (80 meters with 4 feet of width) and mean daily temperature was 29°C to 40°C with relative humidity ranged 60% to 65%. The tabulation of annual rainfall was 2369 mm and average monthly temperature was 26.9 °C. Meanwhile the planting material used in this study is *Capsicum annuum L. Var. Kulai*. The seed was 461 Sakata Hot Pepper F1 Hybrid from Pewaris Bumi Hijau Sdn. Bhd.,Telok Panglima Garang,Selangor. The growth media were arranged by factorial experiment were arranged in a Randomized Complete Block Design (RCBD) with three replications for data pH, EC, CEC, exchangable bases, and nutrient content referred to Appendix H. The experimental setup employed a randomized complete block design (RCBD) with three replications to collect data on various parameters, including plant height, stem diameter, days of flowering, yield quantity and weight, total leaf area, chlorophyll content, root length, root diameter, root surface area, root volume, leaf dry weight, root dry weight, and stem characteristics. The experimental lay out was presented in Appendix E.

5.2.2 Soilless Growth Media and Method of Application

Coconut coir-dust, coconut shell ash, and palm kernel shell biochar derived from coconut and oil palm agricultural residues were used as planting media in this study. The preparation of soilless growth media as shown in Table 3.1 using the method mentioned in section 3.1.1 and placed the mixed soilless media into the polybag of size 40 cm × 40 cm. The growth media were arranged in randomized complete block design (RCBD) arrangement with four replications and polybag distance at 2 m x 2 m. The plants were established for a period of four months and throughout the study period, the data on soilless media properties, growth and physiological status were taken as an indicator to determine the effect of different rate of growth media on *Capsicum annuum* growth performance in fertigation system.

5.2.3 Media Analysis

5.2.3.1 pH and Electrical Conductivity

The soil pH and electrical conductivity were measured using the method mentioned in section 3.2.5.

5.2.3.2 Total Organic Carbon, Nitrogen, and Sulfur

The total organic carbon, nitrogen and sulfur were determined by using the CNS TruMac Determinators (LECO) as mention in section 3.2.6.

5.2.3.3 Cation Exchangeable Capacity (CEC) and Exchangeable Cations

The CEC and exchangeable cations (K^+, Ca^{2+}, Mg^{2+}, and Na^+) was determined using 1M NH4OAc buffered at pH 7.0 as extractant by using leaching method as mentioned in section 3.2.7.

5.2.3.4 Nutrient Content

The nutrient contents of growth media were determined by using the method as referred in section 3.2.8.

5.2.4 Plant Growth Characteristics

5.2.4.1 Sowing and Transplant the Seedling

The sowing and transplant the seedling were using the method mentioned in section 3.3.1

5.2.4.2 Water and Fertilizer Application

The application of water and standard AB chemical liquid fertilizer were irrigated using the method mentioned in section 3.3.2 to the plant and provide the nutrient essential for plant growth. Application of Cooper Formulation solution as refer in Appendix D was applied to the plants twice per day at 8 am in the morning and 5 pm in the evening. Three different rates of AB chemical liquid fertilizer (100% of fertilizer rate, 75% of fertilizer rate, and 50% of fertilizer rate) were irrigated to the plant and provide the nutrient essential for plant growth

5.2.4.3 Weed, Pest and Disease Control

The weed, pest and disease control were explained in section 3.3.3.

5.2.5 Measurement of Vegetative Growth

5.2.5.1 Plant Height

The height of the plant was measured using the method mentioned in section 3.4.1.

5.2.5.2 Stem Diameter

The stem diameter of the plant was measured using the method mentioned in section 3.4.2.

5.2.5.3 Days of Flowering

The data pertaining to the number of days to initiation of flowering, 50% of flowering, and initiation of fruit set were determined by using the method as referred in section 3.4.3.

5.2.5.4 Number and Weight of Fruit (Yield)

Number and weight of harvested fruit were determined by using the method as referred in section 3.4.4.

5.2.5.5 Total Leaf Area (TLA)

Total leaf area was determined using the method explained in section 3.4.5.

5.2.5.6 Chlorophyll Content

Leaf chlorophyll concentration was determined by using the method as referred in section 3.4.6

5.2.6 Root Size and Distribution

5.2.6.1 Root Length, Root Diameter, Root Surface Area and Root Volume

The root length, root diameter, root surface area, and root volume were measured by using the method mentioned in section 3.5.1.

5.2.7 Dry Matter Production

5.2.7.1 Root Dry Weight, Shoot Dry Weight and Root to Shoot Ratio

Dry weight of the leaves, stem and roots were obtained by using the method mentioned in section 3.6.1.

5.2.8 Determination of Fruit Nutrient Content

Nutrient content in harvested fruit were determined and analyzed using the method mentioned in section 3.7.

5.3 Statistical Analysis

All the data collected during the study were recorded and analysed using analysis of variance (ANOVA) by Statistical Analysis System (SAS 9.4) for 1 factorial and 2 factorials of randomized completely block design (RCBD) with three replications to determine the significance difference between the growth media means. Differences between means separated using Tukey's Studentized Range (HSD) at $P \leq 0.05$ level.

5.4 Results and Discussion

5.4.1 Soilless Media Analysis

5.4.1.1 pH Value

From Appendix H-a, experiment of variance shown the effect of different growth media was highly significant ($P \leq 0.05$) on pH value when applied the fertilizer and without fertilizer in field by fertigation system. All growth media shown the significant ($P \leq 0.05$) low in pH value when apply the fertilizer except T1(5.58) and T7 (5.56) compared with no added fertilizer (Figure 5.1). T9 contained the lowest pH value of 5.28 when applied the fertilizer compared with other growth media. The optimum pH of *Capsicum annuum* L. is between 5.5 to 6.5 (Burt,2005). Soil pH affects nutrient solubility, and influences the sorption or precipitation of nutrients (Hue,1992). Citak et al. (2011) proven that chemical fertilizer application caused the soil pH to decrease in any growing season. Wasis et al.(2019) also proven that the ex-limestone soil enhanced with coconut shell charcoal and NPK fertilizer has a decreased pH value from 7.42 (control) to 7.03. Moreover, coconut ash and biochar caused low in pH when applied the fertilizer due to low of pH buffering capacity when reduce calcium, magnesium and potassium oxides as buffer solution that lead to acidification of growth media. The extent of soil acidification depends mainly on the pH buffering capacity of soils (Bolan,2003). According to Chandini et al.(2019), the acidification also caused by the over-use of chemical fertilizers (toxicity) and leaching the nutrient. This increases acidity unable the plant directly absorbs the nutrient especially ammonium ions. Besides, nutrient level in growth media will decreased when crop plants get harvested (Chandini et al.,2019). Meanwhile, Krishnapillai et al.(2020) reported that CCD or cocopeat contained high in conserve water, slow evaporation, and reduce nutrient leaching as well as high in pH buffering capacity (high in calcium, magnesium and potassium oxides act as buffering agents), thus it will change to the high pH value in growth media when compared with no added fertilizer.

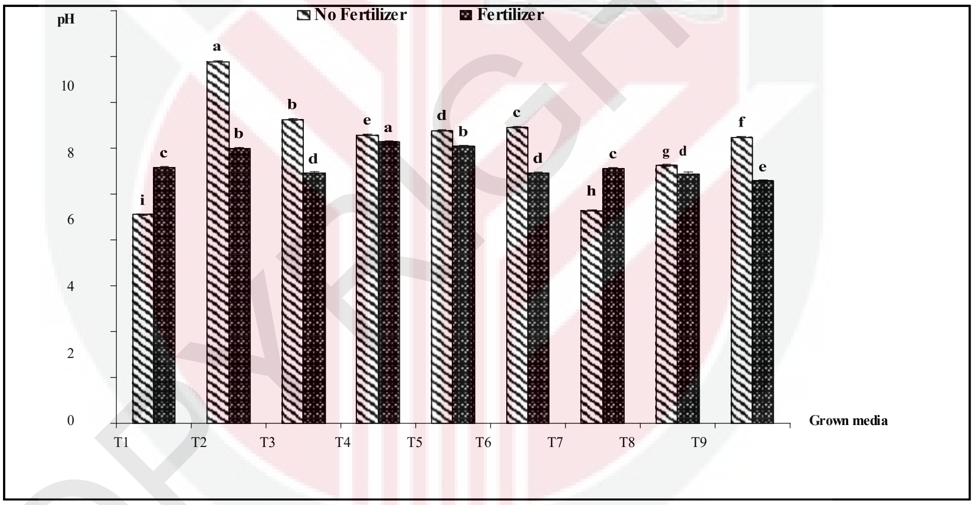


Figure 5.1 : The pH value in different growth media when applied and without fertilizer. ***Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, 6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB.***

5.4.1.2 Electrical Conductivity

The analysis of variance shown the effect of different growth media was highly significant ($P \leq 0.05$) on electrical conductivity (EC) when applied the fertilizer and without fertilizer in field by fertigation system refer to Appendix H-b. Electrical conductivity defined as the current flow and proportional to the total dissolved solids (TDS) in growth media. According to Figure 5.2, all growth media shown the significantly ($P \leq 0.05$) increased in EC when apply the fertilizer except T2 (2.24dS/m) compared with no added fertilizer. The increased of electrical conductivity due to increased level of salts or nutrient concentration in growth media by applied the fertilizer (Othaman et al.,2020). Yahya (2009) reported that the acceptable range of EC in good soilless media should be between 0.4 to 1.5 dS/m. Singh and Bruce (2016) also stated that the optimum EC for *Capsicum annuum* L. is between 0.8 dS/m to 1.8 dS/m. This indicated that all growth media contained a moderate level of nutrient concentration in growth media that ideal for *Capsicum annuum* L. requirement of fertilizer nutrients (Othaman et al.,2020), except for T2(2.24 dS/m), T3(1.80 dS/m), T6(1.91 dS/m) and T9(2.57dS/m) that exceed the acceptable range of EC in soilless media and contained the high salinity (salt-stress) for *Capsicum* crop. It indicated that no further fertilization or reduce the fertilizer rate to avoid from overuse of fertilizers that can lead to salinity build-up in the growth media and plant root damage (Mirzakhaninafchi et al.,2017; Othaman et al.,2020).

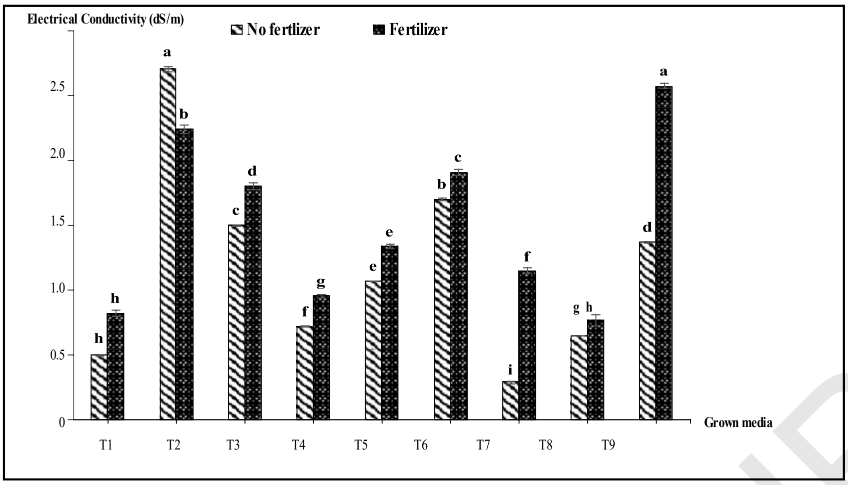


Figure 5.2 ; The electrical conductivity in different growth media when applied and without fertilizer. Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD:1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

5.4.1.3 Cation Exchange Capacity and Soil Exchangeable Bases (K, Ca, Mg and Na)

According to Appendix H-c, the experiment of variance shown the effect of different growth media was significant difference (P≤0.05) on cation exchange capacity (CEC) when applied the fertilizer and no applied the fertilizer in field by fertigation system. CEC refers to the total capacity of growth media to hold, absorb and exchange cations by negative charges in growth media existing on the surfaces of organic matter through electrostatic forces (negative particles attract the positive cations (Shafie et al.,2013). This electrical charge is critical to the supply of nutrients to plants because many nutrients exist as cations such as magnesium, potassium, calcium and sodium (Astera,2010). Moreover, soils with large quantities of negative charge are more fertile due to retain more cations (McKenzie et al., 2004).

The main base cations associated with CEC in soils are the exchangeable cations calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}) (Rayment and Higginson,1992). According to Appendix G-d, the exchangeable cations (K^{+}, Ca^{2+}, Mg^{2+} and Na^{+}) were significantly ($P \leq 0.05$) affected by different growth media before and after application of fertilizer in field by fertigation system. Table 5.1 demonstrated the exchangeable cations (K^{+}, Ca^{2+}, Mg^{2+} and Na^{+}) on different growth media before and after applied the fertilizer. Table 5.1 shown all growth media shown the significantly ($P \leq 0.05$) difference in exchangeable cations (K^{+}, Ca^{2}, Mg^{2+} and Na^{+}) before and after application of fertilizer. All growth media shown the significantly ($P \leq 0.05$) low in exchangeable cations K^{+} after application of fertilizer compared with before applied the fertilizer except exchangeable cations K^{+} in T4 (2.92 cmolc/kg).

Meanwhile, all growth media also shown the significantly ($P \leq 0.05$) high in exchangeable cations Ca^{2+} and Mg^{2+} after application of fertilizer compared with before applied the fertilizer as refer in Table 5.1. All growth media shown the significantly ($P \leq 0.05$) low in The exchangeable cations Na^{+} shown the significantly ($P \leq 0.05$) high affected by differences growth media after application of fertilizer compared with before applied the fertilizer except exchangeable cations Na^{+} in T2 (0.14cmolc/kg), T3 (0.04cmolc/kg), T8 (0.13cmolc/kg), and T9 (0.008cmolc/kg). Figure 5.3 shown all growth media shown the significantly ($P \leq 0.05$) high in CEC when apply the fertilizer except CEC in T2 (8.64 cmolc/kg) compared with no added fertilizer. T1 indicated as the highest CEC (15.64 cmolc/kg) when applied fertilizer, followed by T5(13.0

cmolc/kg) and T7 (13.2cmolc/kg) compared to other growth media. T1 increased about 44% of CEC by applied the fertilizer (15.64 cmolc/kg) compared without fertilizer (10.86 cmolc/kg) due to increase of exchangeable cations (Ca^{2+} , Mg^{2+} and Na^{+}), and pH level (decreasing the concentration of H^{+}, Al^{3+} and Mn^{2+}acid cations) in growth media after application of fertilizer (Quirine,2007). The negative charged particles in organic matter are a result of the dissociation of organic acids and this dissociation depends on the soil pH (Quirine,2007). Logan et al.(1985) and Wang et al.(2009) studied that physical and chemical properties of growth media such as OM, pH, particle size composition have significant effects on CEC. The number of negative charges on the colloids increase when pH increases (becomes less acid). In contrast, the low of CEC in T2 after application of fertilizer caused by decreased of high amount of exchangeable cations K^{+} and Na^{+}, as well as decreased in pH level as growth media become more acidic as many of exchangeable base cations are replaced by H^{+}, Al^{3+} and Mn^{2+} (McKenzie et al.,2004).

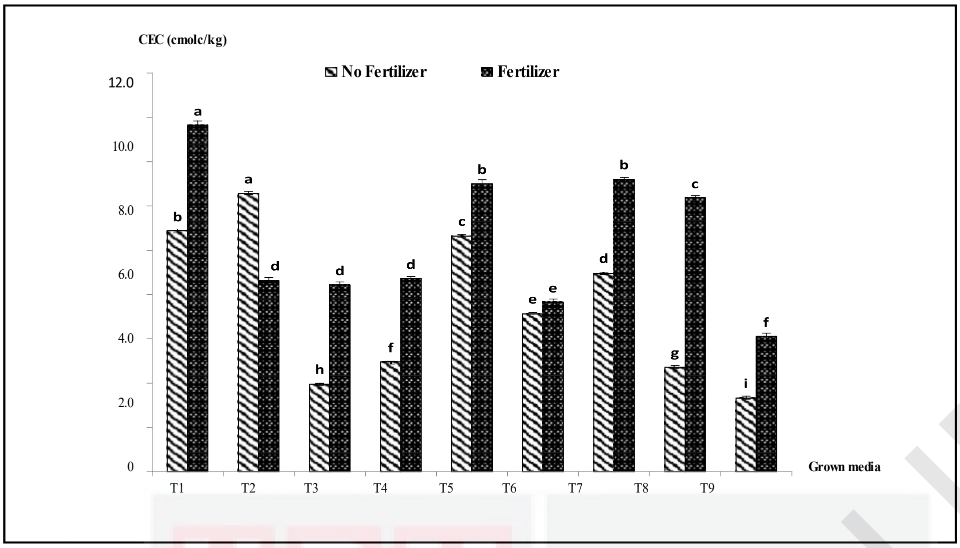


Figure 5.3 : The Cation Exchange Capacity (CEC) in different growth media when applied and without fertilizer. Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD:1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

Table 5.1 : The exchangeable cations K, Ca, Mg, and Na in different growth media before and after applied the fertilizer

Growth media	Concentration Before (cmolc/kg)				
	K	Ca	Mg	Na	K
T1	1.01 ± 0.001^{e}	2.76 ± 0.007^{d}	0.46 ± 0.000^{bc}	0.074 ± 0.002^{f}	0.67 ± 0.002^{c}
T2	3.07 ± 0.003^{a}	2.71 ± 0.012^{ef}	0.52 ± 0.000^{a}	0.21 ± 0.004^{b}	0.35 ± 0.002^{e}
T3	0.73 ± 0.003^{h}	2.68 ± 0.004^{fg}	0.23 ± 0.003^{e}	0.060 ± 0.000^{g}	0.31 ± 0.001^{f}
T4	1.00 ± 0.001^{e}	2.66 ± 0.019^{g}	0.30 ± 0.001^{d}	0.33 ± 0.001^{a}	2.92 ± 0.009^{a}
T5	1.31 ± 0.003^{b}	2.68 ± 0.006^{fg}	0.53 ± 0.005^{a}	0.11 ± 0.003^{d}	0.44 ± 0.001^{d}
T6	1.11 ± 0.001^{c}	2.81 ± 0.016^{c}	0.46 ± 0.005^{b}	0.048 ± 0.002^{h}	0.43 ± 0.003^{d}
T7	1.04 ± 0.004^{d}	2.71 ± 0.006^{e}	0.45 ± 0.005^{c}	0.10 ± 0.000^{e}	0.22 ± 0.002^{g}
T8	0.97 ± 0.000^{f}	2.87 ± 0.009^{b}	0.29 ± 0.005^{d}	0.18 ± 0.003^{c}	1.62 ± 0.005^{b}
T9	0.86 ± 0.003^{g}	2.96 ± 0.011^{a}	0.29 ± 0.003^{d}	0.022 ± 0.001^{i}	0.02 ± 0.001^{h}
HSD (P<0.05)	1.51***	0.03***	0.04***	0.03***	2.57***

Means with different letters are significantly different at P<0.05 using Tukey's Studentized Range (HSD). * and *** significantly different at P≤0.05, and 0.001 respectively and NS= not significant. Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD:1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB.

5.4.1.4 Nutrient Content

The analysis of variance of nutrient content and C:N ratio in organic matter showed significant (P≤0.05) affected by different growth media as shown in Appendix H-e to Appendix H-g). Appendix H-e to Appendix H-g justify that the concentration of C, N, S, P, K, Ca, Fe, Mg, Zn, Al, Mn, Na and C:N ratio in all growth media showed significant (P≤0.05) differences by applied the fertilizer and without fertilizer in field by fertigation system. Table 5.2 shown the nutrient content in different growth media when applied the fertilizer and without fertilizer. According to Table 5.2, all growth media contained high concentration of N (%), S (%) and P when applied the fertilizer compared to concentration of N (%), S (%) and P without application of fertilizer. N and P are the essential macronutrient for plant growth and development in growth media (Razaq et al.,2017). Furthermore, Sulphur is an essential nutrient element playing a pivotal role in protein synthesis, chlorophyll formation and oil synthesis (Rai et al.,2020). Mahajan et al. (2014) reported that the high N, P and S content in growth media was developed by addition of increasing levels of fertilizers and relatively high availability of nutrients from applied fertilizer. Moreover, the high Na content was recorded in all growth media except T2 when applied the fertilizer compared to Na content in without fertilizer. The increase of Na content will increase the EC level and salinity in growth media due to increasing NaCl concentration (Ding et al.,2018; Montaña et al.,2014). Meanwhile, C: N ratio in all growth media become lower when applied the fertilizer than without fertilizer due to low concentration of CO_2 concentration and increased in the N supply in growth media when supply the fertilizer except carbon content in T1 and T4 (Zheng et al.,2018). Table 5.2 also shown that T1 contained high concentration of K, Ca, Fe, Mg and Al, then low concentration of Zn and Mn when applied the fertilizer compared to without fertilizer.

Moreover, high concentration of K, Ca, Fe, and Mn found in T4 when applied the fertilizer. Kalaivani and Jawaharlal (2019) found similar result of increasing K, Ca, Fe, Mg content occur in cocopeat and media combinations after planting by compared with K, Ca, Fe, Mg content in cocopeat before planting. It due to application of fertilizer cause the increase nutrient level in soilless growth media (Baligar et al.,2001). Meanwhile, low concentration of Ca, Mg, Zn, Mn and high content of K, Fe, and Al resultant in T2 when applied the fertilizer compared to without application of fertilizer. According to Table 20, T3 contained high concentration of Fe, Al and Mn, then low concentration of K, Ca, Mg, Zn when applied the fertilizer. Moreover, the high content of Mn and low content of K, Ca, Mg, Fe, Al and Zn in T6 resultant by application of fertilizer. High concentration of K, Ca, Fe, Mg, Zn, Al, and Mn found in T8 when applied the fertilizer. Meanwhile, T9 contained in high concentration of Ca, Fe, Zn, Al, and Mn by application of fertilizer compared to without fertilizer.

It indicated that the application of fertilizer affects the pH value cause by low release of alkalinity attributed to the basic cations such as Ca, Mg, K and Na, and replaced by hydrogen ions that resultant in decreased of pH value (Xu et al.,2006). Ifansyah (2014) reported that phosphate ions react with aluminum (Al) and iron (Fe) to again form less soluble compounds at low pH values. According to Sainju et al.(2003), the normal range of pH for optimum growth of Solanaceae family such as pepper and tomato is from 5.5 to 7.0. Additionally, pH range in soilless substrate was influenced by salinity in applied fertilizer concentration (Smith et al.,2004). Kalaivani and Jawaharlal (2019) also reported that the media combinations with high salinity resultant in low pH value. The high salinity levels of nutrient solution lead to negative impact on nutrient uptake, and shoot and root nutrient content that cause increasing of toxicity and nutrient imbalances (Chondraki et al.,2012). T5 demonstrated as high concentration of Ca, Fe, Mg, Zn, Al, and Mn by application of fertilizer compare to without fertilizer. However, T5 contained the low concentration of K after application of fertilizer. Table 5.2 illustrated that T7 contained higher concentration of Ca, Fe, Zn, Al, Mn and lower concentration of K and Mg when applied fertilizer than nutrient concentration without fertilizer. Furthermore, all growth media have less than or equal to 0.01mg/l of other nutrient content by refer to Table 5.2. Pepper require a sufficient (not excessive) supply of essential mineral elements for optimal productivity. Macronutrients N, P, K, Ca, Mg, and S are needed in large amounts for optimum production, meanwhile micronutrients such as Fe, Mn, Zn, Al and Na are needed in small amounts (Sainju et al.,2003). Crop production is often limited by presence of excessive concentrations of potentially toxic mineral elements in the growth media. High concentrations of mineral elements in growth media can inhibit plant growth and reduce crop yields (MacNicol and Beckett, 1985; Mengel et al., 2001; Marschner, 2011). High N level in growth media can promote excessive vegetative growth which can delay the setting and maturity of fruits, thereby reducing the crop production (Kaniszewki and Elkner,1990; Winsor et al.,1967). Nitrogen is a constituent of protein and amino acids, without which vital functions in the growth and reproduction of plants would not be possible (Winsor, 1973). As N applied from fertilizers to growth media is readily converted into NO_3 for plant uptake, high rate of N fertilization can result in large amount of residual NO_3 build up in the soil after crop harvest because NO_3 is soluble in water, high concentration of residual NO_3 can increase the potential for N leaching from growth media. Potassium helps in vigorous growth of plant and stimulates in early flowering and setting of fruits, thereby increasing the number and production (Varis and George,1985).

Potassium nutrition can affect the quality of fruit. It helps to activate enzymes and is required for carbohydrate metabolism and translocation, nitrogen metabolism and protein synthesis, and regulation of cell sap concentration (Gould,1983). It also increases the concentrations of citric and malic acids, total solids, sugars, and carotene in fruits, thereby improving its storage quality. Phosphorus helps to initiate plant root growth and therefore aids in early establishment of the plant immediately after transplanting or seeding. The vigorous root growth stimulated by P helps in better utilization of water and other nutrients in growth media and promotes a sturdy growth of stem and healthy foliage (Nelson et al.,2011). Phosphorus is a component of nucleic acid. It helps in the production of large number of blossoms in the early growth of pepper and early setting of fruits and seeds (Xu et al.,2001). As a result, it increases the number and production of crop fruits, with increased total soluble solids and acidity contents. It also improves the color of skin and pulp, taste, hardiness, and vitamin C content. Excess level of P can reduce the availability of some micronutrients, such as Fe, Zn, Mn, and Cu, by decreasing their solubility in growth media and translocation within the plant (Needham,1973). The toxic concentrations of Mn, aluminium (Al), sodium (Na), and Fe affect crop production and resultant in toxicities of particular mineral elements such as Ni, cobalt (Co) and chromium (Cr) toxicities (Von Uexku¨ ll & Mutert, 1995; Marschner, 1995). Crop production on acidic growth media is primarily limited by Al and Mn toxicities (Mengel et al., 2001; Marschner, 2011).

The presence of excessive Al in the rhizosphere inhibits root elongation (Mengel et al., 2001; Marschner, 2011). Mn is required by plants for the manganese-protein in photosystem II and the manganese-containing superoxide dismutase and also acts as a cofactor for a number of enzymes that catalyse redox, decarboxylation and hydrolytic reactions (Marschner,2011). Excessive Mn^{2+} is toxic because it can displace Ca^{2+}, Mg^{2+}, Fe^{2+} and Zn^{2+} in essential cellular functions, and generate reactive oxygen in the cell wall. Ca and Mg are applied for increase the pH level (liming) in growth media. High concentration of free $CaCO_3$ in the soil can decrease P availability, Fe and Mn. Magnesium is a component of chlorophyll, pectin, organic acids, and conferment. Lu et al.(2021) reported that fruit production of tomato is significantly increased by applying Mg fertilizer. Iron is a constituent of many enzymes in the nutritional metabolism of crops. Excess level of P in the soil can decrease the solubility of Fe nutrient. Zinc is a constituent of enzyme (carbonic anhydrase) essential for metabolism of nutrients in pepper. High Zn level in the growth media can be toxic to pepper. Affected plants are stunted and spindly with smaller leaves. Younger leaves show interveinal chlorosis and purpling undersides, meanwhile older leaves curl downwards.

Table 5.2 : The nutrient content in different growth media when applied the fertilizer and no applied

Growth media	Fertilizer	Element												
		C (%)	N (%)	C/N	S (%)	P (mg/l)	K (mg/l)	Ca (mg/l)	Fe (mg/l)	Mg (mg/l)	Zn (mg/l)	Al (mg/l)	Mn (mg/l)	Na (mg/l)	Ot her
T1	No	43.33±	0.41±	105.32	0.10±0.	2.85±	149.6±	43.59±	5.74±0.	11.95±	0.22±	4.14±0.	0.13±	23.07±	≤0.
	fertilizer	0.002i	0.000e	±0.004h	002c	0.000g	0.001b	0.000b	003i	0.006g	0.000g	001i	0.000i	0.002e	1
	Fertilizer	51.50±	0.52±	99.04	0.10±0.	8.82±	207.85	199.3	25.92±	12.55±	0.096	61.11±	0.12±	25.13±	≤0.
		0.030i	0.003c	±0.52g	004f	0.003b	±0.036a	±0.230a	0.035i	0.010c	±0.00 2g	0.017e	0.002h	0.044e	1
T2	No	59.48±	0.58±	102.09	0.15±0.	13.9±	191.7	62.40±	71.10±	36.67±	7.63±	101.2	3.30±	53.33±	≤0.
	fertilizer	0.000f	0.001a	±0.14i	001a	0.002a	±0.000a	0.000a	0.004a	0.003a	0.001a	±0.000a	0.002a	0.000a	1
	Fertilizer	55.62±	0.68±	81.79	0.16±0.	14.6±	205±0.	39.28±	147±0.	17.19±	2.58±	319.8±	2.20±	45.35±	≤0.
		0.053e	0.002a	±0.32i	003a	0.003a	111b	0.020g	173a	0.010b	0.065a	0.154a	0.003b	0.050a	1
T3	No	73.96±	0.32±	232.33	0.079±	4.22±	62.88±	42.94±	47.09±	17.66±	0.57±	13.54±	0.88±	8.56±0.	≤0.
	fertilizer	0.004a	0.001g	±0.83a	0.000e	0.000e	0.000f	0.001c	0.001c	0.002b	0.000e	0.000e	0.001b	000h	1
	Fertilizer	64.25±	0.48±	133.86	0.13±0.	5.01±	53.90±	33.07±	62.67±	5.86±0.	0.52±	70.39±	1.82±	15.49±	≤0.
		0.046b	0.002f	±0.48d	002c	0.006f	0.036g	0.017h	0.017c	002i	0.001d	0.010d	0.003c	0.020g	1
T4	No	50.59±	0.45±	113.79	0.10±0.	4.59±	96.68±	21.87±	30.58±	12.10±	0.69±	55.92±	0.51±	27.64±	≤0.
	fertilizer	0.010h	0.000d	±0.031g	002c	0.001d	0.002e	0.001h	0.000e	0.000f	0.002c	0.003d	0.000e	0.001c	1
	Fertilizer	55.03±	0.50±	110.06	0.12±0.	5.83±	130.75	48.91±	32.54±	11.73±	0.11±	7.18±0.	0.60±	28.65±	≤0.
		0.020f	0.002e	±0.38e	003d	0.002e	±0.050c	0.030f	0.017g	0.020d	0.002g	003i	0.003g	0.010d	1
T5	No	57.47±	0.46±	125.56	0.11±0.	5.15±	116.7	24.81±	32.91±	12.48±	0.66±	65.63±	0.52±	27.45±	≤0.
	fertilizer	0.011g	0.000c	±0.025f	001b	0.003c	±0.012d	0.002g	0.003d	0.003d	0.000d	0.002c	0.000d	0.003d	1
	Fertilizer	53.11±	0.57±	93.18	0.16±0.	7.75±	92.60±	75.15±	103±0.	19.77±	1.38±	99.98±	3.53±	32.57±	≤0.
		0.017g	0.002^{b}	±0.31h	002a	0.003d	0.035e	0.010d	100b	0.026a	0.022b	0.036b	0.006a	0.020c	1
T6	No	63.97±	0.48±	132.06	0.10±0.	5.26±	126.5	26.45±	64.97±	13.70±	1.37±	97.62±	0.63±	29.85±	≤0.
	fertilizer	0.008e	0.002b	±0.56e	000c	0.000b	±0.003c	0.003f	0.002b	0.000c	0.002b	0.002b	0.002c	0.002b	1
	Fertilizer	52.73±	0.51±	103.39	0.13±0.	8.45±	92.00±	18.15±	48.35±	8.39±0.	0.40±	79.36±	2.19±	35.27±	≤0.
		0.030h	0.003d	±0.48f	002c	0.004c	0.050f	0.020i	0.030e	002f	0.002e	0.017c	0.006b	0.020b	1
T7	No	65.14±	0.30±	220.97	0.084±	2.05±	40.74±	17.21±	15.12±	9.23±0.	0.24±	4.93±0.	0.31±	8.549±	≤0.
	fertilizer	0.012d	0.002h	±1.52b	0.000e	0.003i	0.003i	0.000i	0.000h	003i	0.003f	003g	0.002h	0.001i	1
	Fertilizer	64.10±	0.45±	142.45	0.15±0.	4.04±	40.37±	78.14±	57.59±	6.58±0.	0.43±	14.38±	1.49±	13.92±	≤0.
		0.046c	0.002g	±0.73c	002b	0.002g	0.026h	0.020c	0.030d	002g	0.004e	0.010f	0.003e	0.030h	1
T8	No	66.05±	0.32±	205.58	0.090±	2.31±	42.24±	28.07±	22.95±	10.27±	0.22±	6.07±0.	0.38±	8.897±	≤0.
	fertilizer	0.006c	0.002g	±0.98d	0.001d	0.002h	0.002h	0.003e	0.002f	0.000h	0.001g	005f	0.003g	0.002g	1
	Fertilizer	65.44±	0.38±	172.22	0.11±0.	2.92±	102.6	103.8	31.11±	11.39±	0.22±	11.03±	1.04±	13.62±	≤0.
		0.017a	0.003i	±1.17a	004e	0.003i	±0.046d	±0.050b	0.040h	0.010e	0.002f	0.010g	0.001f	0.040i	1
T9	No	73.84±	0.35±	214.35	0.077±	3.29±	55.69±	28.37±	22.65±	12.23±	0.20±	4.31±0.	0.47±	9.754±	≤0.
	fertilizer	0.000b	0.000f	±0.044c	0.002e	0.001f	0.001g	0.002d	0.002g	0.000e	0.000h	000h	0.001f	0.000f	1
	Fertilizer	63.80±	0.42±	151.91	0.13±0.	3.79±	28.99±	60.22±	38.66±	6.43±0.	0.66±	10.13±	1.70±	21.31±	≤0.
		0.046d	0.002h	±0.53b	003c	0.001h	0.018i	0.010e	0.026f	002h	0.004c	0.017h	0.002d	0.010f	1

Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD:1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

5.4.2 Plant Growth Characteristics

5.4.2.1 Plant Height

According to Appendix I-a, the analysis of variance demonstrated the effect of different growth media was significant difference ($P \leq 0.05$) on plant height across the week after transplant (WAT). However, the effect of different growth media was no significant difference on plant height at 2WAT. Figure 5.4 represented all growth media shown the significantly ($P \leq 0.05$) increased in plant height from 2WAT to 16WAT. Meanwhile, the Plate 5.1 shown the plant growth during 14 weeks of planting (start transplant the seedling at age 21days). The plant height in all growth media also shown in upward trend that indicated as the increased of plant height and plant mass occur across the week of transplants. Figure 5.4 demonstrated that T1 reached the high plant height of chilli from 2WAT until 16WAT compared to other growth media. The highest plant height in T1 was 57cm at 16WAT, followed by T5 and T7 that reached the plant height of 55.0cm and 52.0cm at 16WAT.

Cocopeat increased the plant height due to contained the acceptable pH, high in CEC, moderate of electrical conductivity, high-water holding capacity and high in N, P, K and the micronutrients Fe, Ca, and Mg (Savithri et al., 1993; Evans et al., 1996; Abad et al., 2002; Awang et al., 2009). Coconut peat can improve moisture retention capacity, increase available nutrient content, infiltration rate, total porosity, and hydraulic conductivity of soil (Savithri and Khan,1993; Abad et al.,1995; Khan et al.,2019). Awang et al. (2009) found that 100% cocopeat resulted in high plant height of *Celosia cristata* with 64.27cm at day 42 after transplanting. Moreover, Treder (2008) found the highest plant height (77.7cm) of *lily* 'Star Gazer' was grown in cocopeat with addition fertilizer (240N:48P:240K). Putra et al.(2017) reported that growth media (cocopeat:soil:manure) shown increased pattern of the plant height of ornamental chilli "Syakira" and "Ayesha"at 2 to 12 week after transplant (WAT). The similar result also found by Nagaraj et al.(2017) when cocopeat resulted in increased trend of plant height of Bell Pepper(*Capsicum annuum Var*. Grossum) at 30, 60, 90, and 120 days after transplant (DAT) and the demonstrated as the second highest of plant height at final harvest (150DAT) compared with sandy loam soil.

Then, the lowest of plant height reached by T8(27cm) at 16WAT. According to the line graph in Figure 5.4, the less use of coconut ash and palm kernel shell biochar can increase the plant height by application of fertilizer dueto high salinity in growth media that affect the pH and CEC to become decrease (Van Tanand Thanh, 2021). Excess fertilizer application would result in low water availability to plant due to high osmotic conditions in growth media, thus it will stunt the plant growth (Studer et al.,2007). The similar result reported by Du et al. (2021) when the shortest plant height of tomato (122.4cm)[4] resultant from application of 1875 kg/ha of fertilizer rate compared with the tallest plant height of tomato (128.4cm) when apply 1140 kg/ha of fertilizer rate. Growth media with a high accumulation of salt will hinders crops growth by introducing excess salt in the root which reduces the amount of water available to the plant (Dudley,1994). Moreover, growth media that contain high levels of Na^+ ions will cause the disturbance and imbalance in the uptake of water and nutrients for crops and disadvantages in soil physical properties (Ağar,2011; Grattan and Grieve,1999)or directly exert toxicity in plants by excessive absorption of ions such as Na^+, Cl^-, B^+, and SO^{2-} (Balba,2018; Bauder et al.,2004; Sheldon et al.,2004; Van Tan and Thanh, 2021).

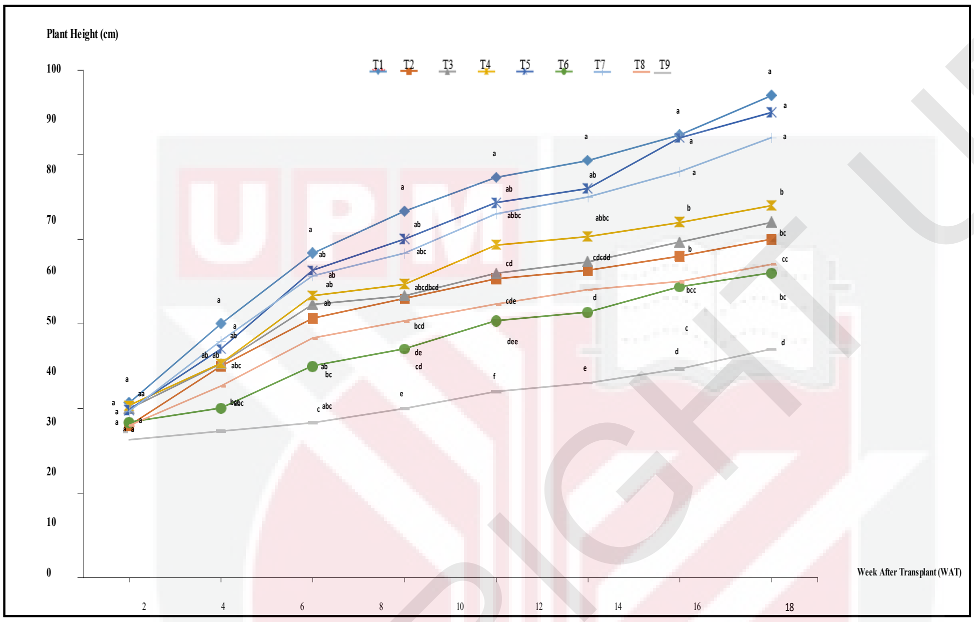


Figure 5.4 : The effect of different growth media on plant height along the week after transplant (WAT). Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD:1PKSB, T8=2CCD:1PKSB, T9=1CCD :1PKSB

Plate 5.1 : Plant growth during 14 weeks of planting (start transplant the seedling at age 21days). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD:1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

5.4.2.2 Stem Diameter

The analysis of variance shown that the effect of different growth media was significant difference ($P \le 0.05$) on stem diameter across the week after transplant (WAT) by refer to Appendix I-b. However, the effect of different growth media was no significant difference on stem diameter at 2WAT. According to Figure 5.5, all growth media shown the significantly ($P \le 0.05$) increased in stem diameter at 2WAT to 16WAT. The stem diameter of chilli in all growth media also shown in increase trend across the week of transplants. Emir et al., (2018) found that plant height and stem diameter of chili pepper increased in each week of observation. The similar result also reported by

Anggraheni et al. (2019) the stem diameter of Chili Pepper significantly increased on each treatment observed at 30 DAP, 60 DAP, and 90 DAP.

Figure 5.5 indicated that T2 reached the highest stem diameter of 12.37mm at 16WAT, followed by T1 with 12.26mm of stem diameter at 16WAT compared with other growth media. Du et al.(2021) found the similar result that the highest stem diameter (14.27mm) with the low of plant height (125.6cm) of tomato when apply 990kg/ha of fertilizer rate tallest plant height (128.4cm), meanwhile the highest plant height (128.4cm) of tomato reached by apply 1140kg/ha of fertilizer rate but contained low of stem diameter with 13.44mm. Fertilizer application vary the availability of NPK in root zone and uptake of nutrients to the plant organs (Du et al.,2021; Zhang et al.,2018; Li et al.,2018). T1 (100% cocopeat) reached the optimum balance condition among nutrients in growth media which eventually resulted in high stem diameter and plant height (Awang et al.,2009). Then, T8 demonstrated as the lowest of stem diameter (8.56mm) at 16WAT compared to other growth media. The differences of stem diameter between T2 and T8 was 44.5% at 16WAT. The similar result reported by Baon (2009) where the lowest stem diameter (7.74mm) and plant height (33.35cm) of cocoa when applied 1500 mg K_2O applied as PDAsh per 2.5 kg soil, meanwhile the highest stem diameter (9.34mm) and plant height (43.81cm) found when applied 900 mg K_2O applied as PDAsh per 2.5 kg soil.It causes due to high salinity or concentration of K nutrient in growth media (Baon,2009). Plant height and stem diameter were influenced by K nutrient uptake (Hartatik et al., 1999). K nutrient play a role in accelerating growth of meristem tissues (Marschner, 1995).

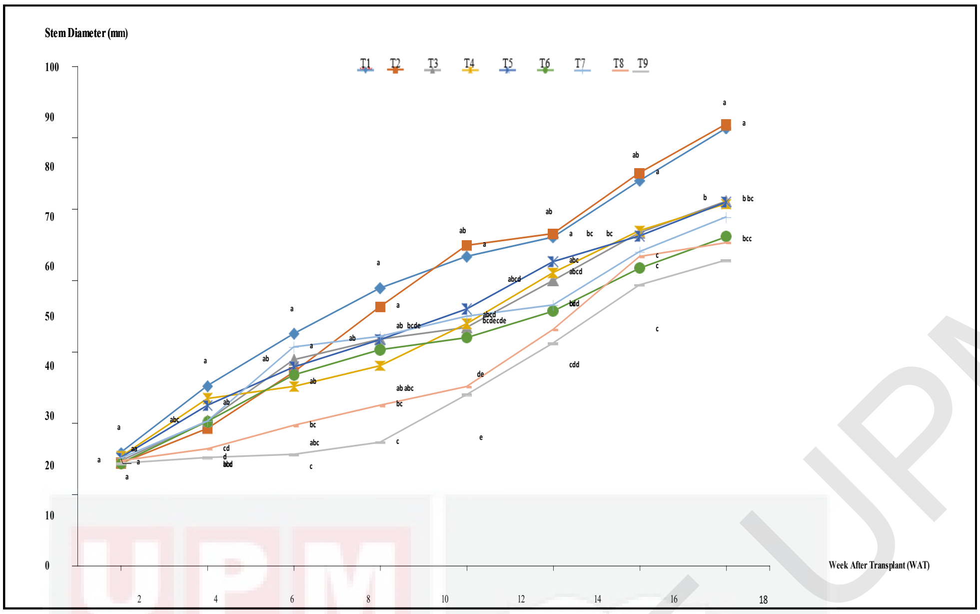


Figure 5.5 : The effect of different growth media on stem diameter across the week after transplant (WAT). Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

5.4.2.3 Days of Flowering

Table 5.3 shown the day of flowering at different flowering stages in different growth media. The flowering stages on chilli plant that be analyze in this experiment consist of initial flowering, 50% of flowering, and fruit set. The analysis of variance demonstrated the effect of different growth media were significant difference (P≤0.05) on day of flowering at initial flowering and 50% flowering by refer to Appendix I-c. However, the analysis of variance indicated that the effect of different growth media was no significant difference (P≤0.05) on day of initial fruit set (Appendix I-c). similar result found by Arrington (2017), there was no significant differences of foliar applications of Ca and B on initial fruit set of blueberries. It indicates that different growth media did not improve to initial the fruit set of chilli.

The initial fruit set potentially influences by air temperatures, weather conditions, foraging activity of pollinators, pollination and fertilization rate (Seeley 2009; Tuell and Isaacs, 2010; Courcelles et al., 2013). According to Table 5.3, T1 had early flowering at the 42.00 days, 46.33 days, and 52.33 days after transplant for initial flowering, 50% flowering, and fruit set stages compared to other growth media. In contrast with T9 that took the longest days at 47.33 days, 52.00 days, and 58.00 days after transplant for initial flowering, 50% flowering, and fruit set stages that resultant in delay of 4 to 6 days of initial flowering in comparison to T1. Lim (2012) reported that the number of days to 50% flowering of *Capsicum annuum L. Var. Kulai* was 39 days after transplant 4 weeks. Thus, the days Kulai Chilli started 50% flowering after transplant the seedling at 21 days was about 46 to 48 days in this study. The availability of good light intensity and sufficient nutrients in the growth media resulting in the accumulation of more photosynthesis and induction of early flowering. The availability of optimal light intensity is paramount for promoting early flowering in plants. Good light intensity, measured in terms of suitable foot-candles or lux levels, ensures that plants receive the necessary energy for robust photosynthesis. Adequate light serves as a key environmental cue that triggers the transition from vegetative growth to the reproductive phase, including the initiation of flowering. The definition of good light intensity for early flowering is intricately linked to meeting the specific light requirements of the particular plant species. This includes providing the right balance of light duration, intensity, and quality, such as the appropriate spectrum of wavelengths. Consistency in maintaining an optimal light environment is equally crucial, as fluctuations in light conditions can disrupt the internal regulatory mechanisms of the plant, potentially delaying or affecting the timing of the flowering process. In essence, ensuring the availability of favorable light conditions is essential for orchestrating the physiological responses that lead to early and successful flowering in plants.

In contrast, the salinity effect on chili plant resulted in a delay of the flowering due to stress condition or diseased attack (Kpinkoun et al.,2019). Salt stress leads to suppression of plant growth and flowering (Khoshsokan et al., 2012). Moreover, Van Zandt and Mopper (2002) reported that salinity strongly delayed flowering phenology mainly in the second year when less than 4.0 g/L NaCl delayed flowering up to 3 days. According to Techawongstein et al. (1992) and Tebal (2011), water availability in the rooting zone profoundly also influenced chili pepper growth and flowering

Table 5.3 : The effect of different growth media on day of flowering at different flowering stages

Growth	Day of Flowering		
	Initial	50%	Fruit set
T1	42.00 ± 0.00^{c}	46.33 ± 0.58^{d}	52.33 ± 1.53^{b}
T2	44.67 ± 0.58^{b}	50.33 ± 0.58^{b}	57.00 ± 1.73^{ab}
T3	44.00 ± 0.00^{b}	49.33 ± 0.58^{bc}	55.67 ± 1.53^{ab}
T4	44.00 ± 0.00^{b}	49.00 ± 0.00^{bc}	55.00 ± 1.73^{ab}
T5	43.33 ± 0.58^{bc}	48.67 ± 0.58^{c}	54.67 ± 1.53^{ab}
T6	46.67 ± 0.58^{a}	50.33 ± 0.58^{b}	56.33 ± 1.53^{ab}
T7	43.33 ± 0.58^{bc}	48.33 ± 0.58^{c}	55.00 ± 2.00^{ab}
T8	44.33 ± 1.15^{b}	49.33 ± 0.58^{bc}	55.00 ± 2.00^{ab}
T9	47.33 ± 0.58^{a}	52.00 ± 1.00^{a}	58.00 ± 1.73^{a}
HSD ($P<0.05$)	8.32***	7.37***	NS

Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). * and *** significantly different at P≤0.05, and 0.001 respectively and NS= not significant. Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA,T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD:1PKSB

5.4.2.4 Number of Harvested Fruit (Yield)

Figure 5.6 represented the number of harvested fruit (yield) in different growth media. According to Appendix I-d, the experiment of variance resulted the effect of different growth media was significant difference (P≤0.05) on number of harvested fruit (yield). T1 exhibited as the maximum number of fruits harvested (yield) of 58, followed by T5 (42) and T7(41) compared to other growth media. The similar result found by Harjoko et al.(2018) that the highest number of Hot Beauty chili harvested fruit production(161) was grown in cocopeat compared with number of harvested fruit in Steamed Ricehusk(115), Steamed Ricehusk with Zeolite(123), and Cocopeat with Zeolite(159) growth media. Sedaghat (2017) also reported that 100% cocopeat growth media produce the high number of tomato yield than 100% Perlite and 25%Cocopeat: 75%Perlite (by volume) growth media. Meanwhile, T6 (15) and T9 (15) contained the minimum number of fruits harvested (yield) compared with other growth media. This indicated that the increased amount of coconut ash and PKSB combine with CCD in growth media will decreased the number of fruits harvested (yield). Meanwhile, the increased amount of CCD in growth media will increased the number and weight of yields due to rich of nutrient content, good aeration and water holding capacity allows the plants better nutrient uptake for sufficient growth and development (Ayesha et al., 2011; Hesami et al., 2012). The increased nutrient concentration of P, K and Ca in cocopeat is associated with increased of flowering and fruit production (Cruz et al.,2019). The cocopeat also contained less acidic with a pH suitable and high CEC to facilitate crops to grow and consequently allows the plant roots to absorb nutrient efficiently (Suhaimi et al.,2012). According to Harjoko et al.(2018), the number of fruit also influence by the successful of formation of the fruit from flowering. The formation of the fruit is determined by the daytime air and night temperature factor. Experience in various countries proves that too high a temperature at night causes *Solanaceae* plants could not form flowers at all, whereas at temperatures less than 100^0C pollen becomes a weak growing and many pollens is dead due to only a few that occur fertilization (Tugiyono,2005). Temperatures that are too high in greenhouses during daytime are thought to cause pollen to fall and fail to pollinate. Lack of pollination can also be caused by limited factors that can help pollination, like wind and insects.

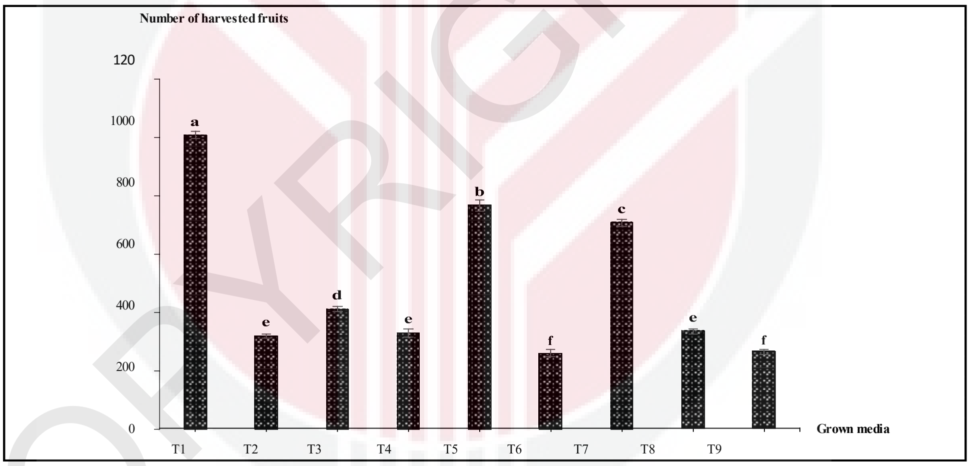


Figure 5.6 : The effect of different growth media on number of harvested fruit (yield). Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

5.4.2.5 Weight of Harvested Fruit (Yield)

Figure 5.7 illustrated the weight of harvested fruit (yield) in different growth media. Appendix I-d justified that the analysis of variance resulted the effect of different growth media was significant difference ($P \leq 0.05$) on weight of harvested fruit (yield). T1 (1008g) indicated as the maximum weight of fruits harvested (yield), followed by T5 (767g) compared to other growth media. According to Sedaghat (2017), the higher weight of tomato yield was grown in 100% cocopeat compare with 100% Perlite growth media. The similar result found by Harjoko et al.(2018) that the maximum weight harvested fruit of Hot Beauty chili (656g) was grown in cocopeat compared with weight of harvested fruit in steamed rice-husk(442g), rice-husk charcoal with zeolite(630g), steamed rice-husk with zeolite(503g), and cocopeat with zeolite(599g) growth media. Raja et al.(2018) also found that cocopeat growth media produce the higher weight of Strawberry fruit (6.74g) than grown in 100%sand, 100%Perlite, 100%Vermiculite, 25%Coco peat : 75%Perlite, 75%Coco peat : 25%Vermiculite, and 75%Perlite : 25%Vermiculite (by volume) growth media. In contrast with T6 contained the least of weight of fruits harvested (yield) of 259g compared with other growth media as refer to Figure 5.7. The difference of weight of fruits harvested between T1 and T6 was about 741g. Suhaimi et al.(2012) proven that growth media containing high amount of coconut coir dust (70% to 100%) showed good growth and increased the ginger rhizome yield (g) up to 36% compared to those containing high amount of burnt paddy husks. It indicated that 100% coconut coir dust or any combinations with high amount of coconut coir dust are the best substrates for growing crops. According to Harjoko et al.(2018), the weight of fruit is proportional to the number of fruits and plant size. Therefore, the high number of fruit (yield) will contain the high weight of yield(g). Meanwhile, the poor growth of plants will yield the less fruits (Hassan et al.,1995).

Yield increases attributed to favorable soil moisture and nutrient utilization (Chalfant et al.,1977). Cocopeat contained high of nutrient content, good aeration and water holding capacity that allows the plants better nutrient uptake for sufficient growth and development (Ayesha et al., 2011; Hesami et al., 2012). The increased nutrient concentration of P, K and Ca in cocopeat increase the flowering and fruit production as well as enhance the plant growth and yield (Cruz et al.,2019; Hassan et al.,1995). Moreover, the reduce yield of the plant also caused by pest attack and diseases infection on chilli crop during vegetative and reproductive stages (Hussain and Abid, 2011). The fruit borer (*Helicoverpa armigera*) and fruit fly (*Bactrocera dorsalis*) mostly attack the fruit during reproductive stage by sucking and damage the fruit that reduce the fruit (yield) quality and production (Sharma et al.,2017). According to Hussain and Abid (2011), the yield of chilli is reducing gradually every year due to different pests and pathogens which cause heavy losses.

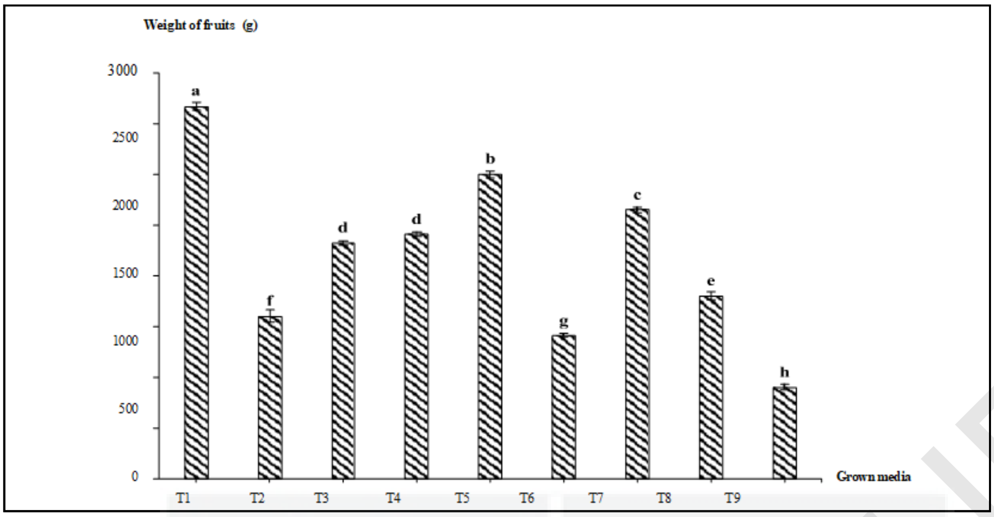


Figure 5.7 : The effect of different growth media on weight of harvested fruit (yield). Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

5.4.2.6 Total Leaf Area (TLA)

The analysis of variance revealed a significant difference ($P \leq 0.05$) in the effect of different growth media on total leaf area (see Appendix I-e). Figure 5.8 illustrates that T1 exhibited the highest total leaf area, constituting 3668.36 cm^2, representing a percentage increase of 34% compared to other growth media. Following closely, T5 displayed a total leaf area of 3000.22 cm^2, corresponding to a 28 % increase, and T7 showed 2646.86 cm^2, indicating a 14% increase. These findings underscore the considerable impact of different growth media on the total leaf area of the chili plants, with T1, T5, and T7 emerging as noteworthy contributors to enhanced leaf development.

Awang et al. (2009) reported that the increased of cocopeat rate in growth media resultant in high total leave area after found the highest of total leave area of *Celosia cristata* grown in 100% cocopeat and 70 cocopeat: 30 burnt rice hulls compared to other growth media. Putra et al.(2020) also found that the high total leave area of potato grown in high cocopeat medium thickness and frequent of fertilizer applied (high concentrations of nutrient solutions). *Aglaonema* grown in cocopeat: sand: vermicompost (2:1:1 ratio, v/v) produced leaves with maximum of number of leaves and total leaf area. It caused by excellent physical (water retention and aeration) and chemical properties (acceptable pH, low electrical conductivity, high CEC) of cocopeat, which would have resulted in higher nutrient uptake (Swetha et al.,2014). Cocopeat affords higher total pore space (TPS) and water holding capacity (WHC). Cocopeat has the ability to store and release nutrients to plants for an extended period of time. Cocopeat allows air, nutrients and water to reach the root surface, which may be one of the reasons for the rapid and vigorous growth of plant. Thus, production of more leaves with maximum leaf area in this medium largely agrees with improved root development (Swetha et al.,2014). Cocopeat is very slow to disintegrate which makes it resistant to bacterial and fungal growth (Cresswell, 2002). This could be one of the reasons for higher root growth.

Then, T9 demonstrated as the lowest of total leaf area (900.67cm^2) compared to other growth media as illustrated in Figure 5.8. Provision of nutrient solutions that are too frequent and high concentrations (salinity) will cause toxicity to plants and inhibit plant growth (Wijayani and Widodo, 2005). Reduction in bell pepper leaf area due to increasing salinity of water or soil has also been observed by Arruda et al.(2011), Sá et al.(2016), Tehseen et al.(2016) and Oliveira et al.(2018). Qiu et al.(2018) and Ullah et al.(2020) reported that the leaf area of hot pepper and tomato declined significantly ($P < 0.05$) as the EC was increased. Ferreira et al.(2020) declared that the most drastic salinity effect occurred at the early stages of the seedlings development, where from 90 mM NaCl up, the reduction in the leaf area was approximately 90% in comparison to that of the control plants. Salinity stress has significant effect on leaf area of tomato plant at higher concentrations which is due to the salinity that effect the nitrogen levels which lead to decrease in rate of photosynthesis and hence decrease leaf area (Kashem et al. 2000). Salinity poses two major threats to plant growth such as osmotic stress and ionic stress (Flower and Colmer, 2008). In addition, it also manifested an oxidative stress.

The deleterious effects of salinity affect different physiological and metabolic processes of plants. The responses to these changes are often accompanied by a variety of symptoms, such as the decrease in leaf area, increase of leaf thickness and succulence, abscission of leaves, necrosis of root and shoot, and decrease of internode lengths (Gucci and Tattini 1997; Parida and Das 2005). Moreover, salt stress significantly reduced leaf area and leaf fresh weight. Salinity affects differently early growth stages of plants. Salinity has both osmotic and specific ion effects on plant growth (Dionisio-Sese and Tobita 2000). Leaf growth inhibition is seen as an adaptive response to salinity and water deficiency. Plants with lower leaf area can cut water losses by slowing transpiration, and thus delay the onset of more severe stress (Casierra-Posada et al., 2006). Increased dead leaves are another contributing factor to leaf area reduction. In fact, the leaf death rate increased in plants experiencing saline stress when compared with control plants.

Increased leaf death under saline stress is generally attributed to toxic levels of salt accumulation (Munns, 2002). López et al. (2011) reported that total leaf area was significantly decreased with increasing salinity levels. The inhibitory effects of salt stress on growth parameters of chili pepper plants were associated to the impacts of high soil salt availability and may either be due to osmotic reduction in water availability or to excessive accumulation of ions, known as specific ion effect (Marschner, 2011). Garcia et al. (2012) affirmed that the decline of the osmotic potential of the soil solution with the increase in salinity of the soil causing the reduction of the water matrix potential, generating a resistance of the plants in absorbing water, and with the increase in the osmotic pressure, the plants will not have efficiency in generation power of suction to overcome this potential, therefore plant will not accomplish to absorb water, affecting the cell expansion causing decrease in the total leave area (TLA). Reductions in leaf area were also observed by Li and Stanghellini (2001) in greenhouse tomato affected by root-zone salinity, and De Pascale et al. (2003) in salt- stressed pepper plants.

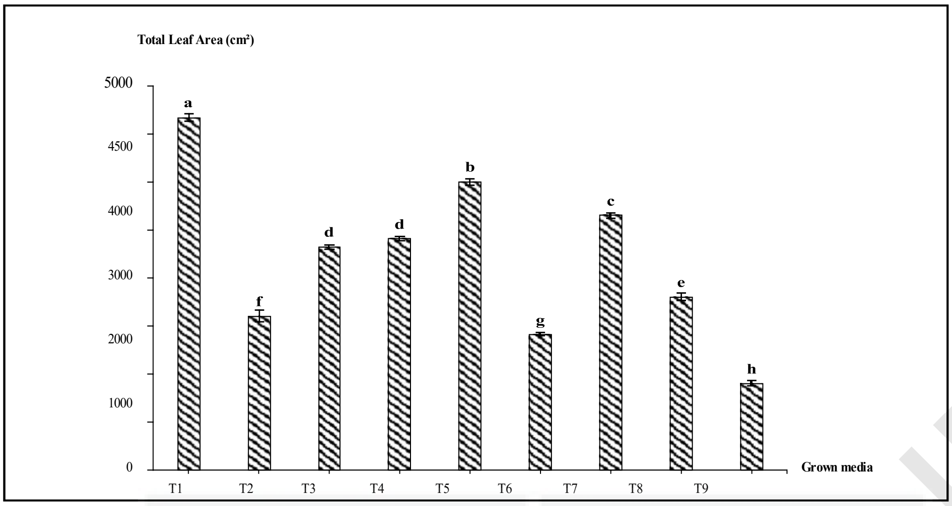


Figure 5.8 : The effect of different growth media on total leaf area of chilli. Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

5.4.2.7 Chlorophyll Content

Appendix I-i justified the analysis of variance, confirming a significant difference (P ≤ 0.05) in the effect of different growth media on chlorophyll content. T1 exhibited the highest chlorophyll content, recording 64.0 units, as illustrated in Figure 5.9. Subsequently, T8 demonstrated the second-highest chlorophyll content at 58.6 units, representing a difference of about 9.22% compared to the chlorophyll content in T1. These results, expressed in percentage terms, emphasize the considerable influence of different growth media on chlorophyll levels in chili plants, with T1 and T8 emerging as notable contributors to enhanced chlorophyll production. Sardoei and Rahbarian (2014) reported that the high total chlorophyll content (21.34mg/ml) in *Rosmarinus officinalis* grown in 100% cocopeat. Sarkar et al.(2021) also found that cocopeat-based growing media attained the maximum value of total chlorophyll (0.66 mg g^{-1}) of Red Leaf Lettuce due to high accumulation of nitrogen in plants. CCD have good aeration, water holding capability, and biostability lead to absorption of N for the chlorophyll development in plant (Rahman et al.,2018). The chlorophyll is an essential component for photosynthesis occurs in chloroplasts a green pigment in all photosynthetic plant tissues, thus more chlorophyll content in plants is attributed to more uptake of nitrogen by the plants (Malik et al.,2011). According to Khandaker et al.(2017), chlorophyll component is made up from nitrogen and it is functioning in promoting vegetative growth and green coloration of plant foliage. Nitrogen involve in the formation of chlorophyll which lead to an effective photosynthesis rate of chilli plant. Albaho et al. (2009) also reported that different growing had significant effects on chlorophyll index of pepper depends on nitrogen uptake by plants. Moreover, the chlorophyll content and rate of photosynthesis are influences by light intensity (Datuk et al., 2020). More light received will promotes higher rate of photosynthesis for plant. Light intensity has linear negative respond to plant shading which meant that a reduced canopy permits more light intensity received in the area (Datuk et al., 2020).

Meanwhile, Figure 5.9 also illustrated that T9 contained the lowest of chlorophyll content (39.0) compared to other growth media due to low of nitrogen uptake by plant, high salinity, and loss of green color (Sedaghat et al.,2017). According to Rusli et al.(2021), the relative chlorophyll content of plants applied with palm kernel biochar decreased at the lowest rate about 10.46% throughout the six months. The lowest impact on the chlorophyll content of biochar applications linked to an increased C: N ratio in biochar, leading to the immobilization of N in growth media and hence the decreased plant uptak of N (Kammann et al., 2011). Additionally, it also attributed to $NH4^+$ adsorption on the biochar surface resulting in less N availability (Lehmann et al., 2002). A decrease of chlorophyll content index in growth media attributed to the decrease of N uptake (Van Hoorn et al.,2001) and the increase of chlorophyllase activity (Reddy and Vora,1986). Moreover, total leaf chlorophyll contents significantly decreased with an increase of salinity levels (Khan et al.,2013). The reduction in photosynthesis under salinity can also be attributed to a decrease in chlorophyll content (Supanjani and Lee, 2006). Chandramohanan et al. (2014) revealed that salt stress resulted in decline in chlorophyll content in all the cultivars. Similar studies were also carried out by Ashraf and Yousafali (1998), and Ali et al. (2004) found that the chlorophyll content (chlorophyll a, b and total) of rice leaves was generally reduced under high salinity. Other researchers report that plants grown under high salinity conditions had lower chlorophyll contents (Perolino and Leone,1980; Grant and Summers,1981). Reduction in chlorophyll concentrations due to the inhibitory effect of the accumulated ions of various salts on the biosynthesis of the different chlorophyll fractions. Salinity affects the strength of the forces bringing the complex pigment protein liquid in the chloroplast structure (Ali et al.,2004). The reduction in leaf chlorophyll content under salinity stress has been attributed to the destruction of chlorophyll pigments and the instability of the pigment protein complex (Leavitt,1980). As the chloroplast in membrane bound its stability is dependent on the membrane stability which under high salinity condition seldom remains intact due to which reduction in chlorophyll was record (Ali et al.,2004). Therefore, it proven that salinity had negative effects on the growth and photosynthetic metabolism of crops (Jaleel et al.,2008). The loss of green color is caused by chlorophyll degradation that is catalyzed by the chlorophyllase that converts the chlorophyll a and b to chlorophyllide and phytol (Matile et al.,1997). The chlorophyll degradation was accelerated in leaves of plants grown using all growing significant decrease in chlorophyll content.

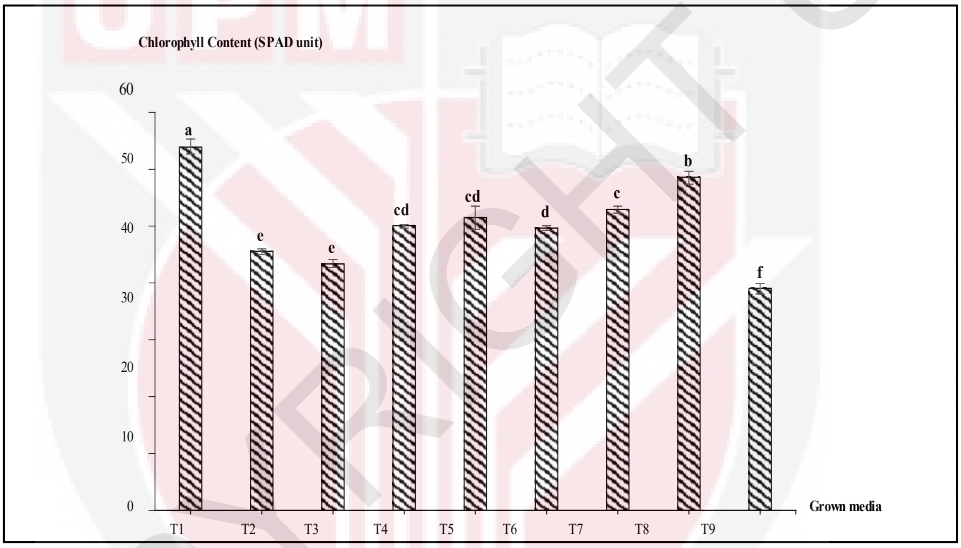


Figure 5.9 : The chlorophyll content in different growth media. Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

5.4.3 Root Size and Distribution

5.4.3.1 Root Length, Root Diameter, Root Surface Area and Root Volume

The analysis of variance demonstrated the effect of different growth media were significant difference (P≤0.05) on root length, root diameter, root surface, and root volume by refer to Appendix I-c. Table 5.4 shown the root length, root diameter, root surface, and root volume in different growth media. According to Table 5.4, the longest of root length was T2 (419.65cm), followed by T3 with 400.21cm of root length compared to other growth media. Root system architecture and expansion is regulated by water and nutrient uptake efficiency (Arif et al.,2019). However, root growth and elongation are affected differently by excess salinity (Kafkafi et al.,2002). Plants use their root plasticity to survive in stress conditions (Bell and Sultan,1999; Kano et al.,2011). Arif et al.(2019) reported that an increase in the length of the third-order lateral root highlights that root system plasticity under salt stress. According to Wang et al.(2009) and Franco et al.(2008), the lateral roots of *Arabidopsis thaliana* and *Silene vulgaris* were found to show promoted elongation. Elongation of roots is the result of cell division and cell expansion in the root apical meristem. Therefore, salinity may alter root elongation either by promoting and reducing cell division and expansion (West et al.,2004).

Moreover, T5 contained the highest of root diameter (1.87mm) and root surface area (245.67cm^2) compared with other growth media as shown in Table 5.4. The capacity for water and nutrient uptake by plant was more closely related to the total surface area of the root system. Tachibana and Ohta (1983) found that increasing in root surface area of cucumber due to increase of water and Ca, K, and P nutrient uptake. This indicated that the high nutrient uptake was related to the increase amount of root membrane and metabolic activity of the specific area of the root surface (Bar-Yosef et al.,1972; Tachibana and Ohta, 1983). The root diameter relates directly to the investment by a plant of biomass in root (Eissenstat, 1992). Hydraulic and nutritional constraints also influence the root diameter (North and Nobel, 1991; Steudle, 2000; Fan et al., 2003; Saengwilai et al., 2014; Lynch et al., 2014). Moreover, Croser et al. (2001) and Franco et al. (2011) also found an increase in root diameter in response to salinity. Meanwhile T1 contained with 10.00cm^3 of root volume, thus T1 be the highest of root volume compared to other growth media. Ghasemi Ghehsareh et al.(2020) found that cocopeat have the highest root volume of miniature roses compare to licorice root residue, peat moss + licorice root residue, and cocopeat + licorice root residue mixtures. This result is consistent with previous indications by Bunt (2012) that CCD can be effective for root development due to good porosity.

CCD also provided better conditions for root growth by providing sufficient water, nutrient and air as well as stimulating root development. Cocopeat is very slow to disintegrate which makes it resistant to bacterial and fungal growth. This could be one of the reasons for higher root growth (Cresswell, 2002). In contrast, T9 demonstrated as the lowest in root length, root diameter, root surface, and root volume as illustrated in Table 5.4. This is mainly due to salt toxicity leading to a decrease in plant water holding capacity, imbalances in nutrient uptake, and the toxicity of ions to plant roots and photosynthesis (Katerji et al.,1998; Van Hoorn 2001). High salinity has been shown to inhibit uptake and transport of N, P, K and Ca (Zhu et al.,2001). Additionally, salinity stress leads to reductions in Zn uptake by plant roots due to Na^+ competition at the root surface (Marschner,1995). Increasing salinity imposed a negative effect (significantly decreased) on root growth include root area, root volume, main root length, total root length, mean root diameter, root dry weight that can lead to root damage (Kafi and Rahimi,2011).

Root K content showed the opposite trend of Na content and it significantly decreased with increasing salinity. Root K/Na ratio was significantly decreased in higher levels of salinity. Main root length and total root length of purslane decreased with salt concentration. Root elongations rate of sunflower decreased with increase in NaCl salinity (Bhutta et al.,2004). Correspondingly, the presence of excessive Al ions in the soil will hinder the growth and development of major crops such as soybean, wheat and maize (Kochian et al., 2004). In addition, the ionic forms of Al reportedly inhibits root growth (Kopittke et al., 2015) and root elongation by destroying the cell structure of the root apex and thus affecting water and nutrient uptake by the roots (Zheng, 2010), and disturbs root functions, such as plasma membrane permeability (Ishikawa and Wagatsuma, 1998), lipid peroxidation (Ikegawa et al., 2000) and cell wall rigidity (Wehr et al., 2004). Sánchez- Blanco et al.(2014) reported that root length is a critical factor in influencing the ability of a plant to absorb water from the growth media under water stress conditions. Total root length decreased by 27% with water stress, a reduction observed in all root sizes. In general, root volume is reduced more than dry weight in stressed plants, meanwhile root density increases under deficit irrigation.

Root length decreased with irrigation solutions of increasing of EC on *Solanum melongena* (Akinci et al., 2004) and *P. oleracea* (Franco et al., 2011). The effect of irrigation with saline water was very similar to water stress, a decrease in total root length and root volume was observed in all root sizes with an increase in the percentage of thick roots and a decreased percentage of fine roots (Sánchez-Blanco et al.,2014). A few contradictory results were reported related to root elongation. The rate of root elongation decreased under salinity stress in rice, wheat, and Arabidopsis (Jones, 1986; Zhu et al.,1998; Jbir et al.,2011). The root variables that contributed to root surface area were found to be reduced under stressed conditions that considering the root surface area is correlated with nutrient uptake potential (Wang et al.,2008; Haling et al.,2013; Robin et al.,2015; Robin et al.,2016; Huang et al.,2013.

Table 5.4 : The effect of different growth media on root length, root diameter, root surface area, and root volume

Growth media	Root Size and Distribution		
	Root Length (cm)	Root Diameter (mm)	Root Surface Area(cm2)
T1	310.84±0.11^{e}	1.86±0.07^{ab}	214.65±0.77^{c}
T2	419.65±0.69^{a}	1.11±0.08^{e}	175.95±2.04^{e}
T3	400.21±4.71^{b}	1.71±0.129^{abc}	176.64±1.10^{e}
T4	320.23±4.81^{e}	1.49±0.21^{bcd}	196.72±4.39^{d}
T5	346.11±1.74^{d}	1.87±0.09^{a}	245.67±2.99^{a}
T6	253.62±1.92^{f}	1.35±0.12^{cde}	142.12±2.75^{f}
T7	366.63±2.83^{c}	1.19±0.07^{de}	232.06±2.62^{b}
T8	358.98±5.75^{c}	1.41±0.21^{cde}	132.06±3.48^{g}
T9	243.61±1.71^{g}	1.10±0.01^{e}	110.67±0.59^{h}
HSD (P<0.05)	10834.00***	0.28***	6399.65***

Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). * and *** significantly different at P≤0.05, and 0.001 respectively and NS= not significant. Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

5.4.4 Dry Matter Production

5.4.4.1 Root Dry Weight, Shoot Dry Weight and Root to Shoot Ratio

As indicated in Appendix I-g, the application of fertilizer in the field through a fertigation system significantly affected ($P \leq 0.05$) the dry weights of leaves, stems, and roots across various growth media. Table 5.5 provides a breakdown of the dry weights for leaves, stems, and roots in different growth media. Among these, T1 exhibited the highest dry weights for leaves (54.37g), stems (60.03g), and roots (23.25g). Following closely, T5 recorded the second-highest dry weights for leaves (42.78g), stems (41.33g), and roots (22.23g) in comparison to other growth media. A study by Khan et al. (2019) similarly observed that the dry weight of Ipomoea aquatica plants increased with the application of 2500 kg coconut peat plant−1. The results highlight the significant impact of different growth media on the dry weights of plant components, emphasizing the notable contributions of T1 and T5. Additionally, previous research by Khan et al. (2019) and Awang et al. (2009) underscores the positive effects of coconut coir dust (CCD) on plant dry weights, indicating that increased application rates enhance both fresh and dry weights per plant, thereby influencing overall plant development. Awang et al. (2009) also noted that the increased rate of cocopeat in growth media led to higher dry weights of stems, leaves, and roots, further supporting the findings in this study.

Swetha et al. (2014) also obtained the maximum dry weight of roots in treatment cocopeat + sand + vermicompost in 2:1:1 ratio (v/v) and cocopeat + sand + FYM + vermicompost in 2:1:1:0.5 ratio (v/v) (8.08g). According to

Alzrog et al. (2013), the maximum shoot and root dry weight per plant of chilli (*Capsicum annum* L.) was grown in coco peat media. The results were similar found by Máthé-Gáspár & Anton (2002), Chaves et al. (2011), and Awotoye, et al., (2009). Adding cocopeat improve soil physical and biological conditions and create a more favorable environment for root growth and nutrients availability, increased plant growth and dry matter (Valiki and Ghanbari,2015; Kaplan et al.,2007). The cocopeat system produced significantly more marketable stems and a higher cumulative stem weight, which resulted in a higher average stem weight (Ketter et al.,2013). The higher cumulative weight and the greater number of stems that were obtained from the cocopeat system due to a higher total dry matter production as a result of better growth environment.

Substrate cultivation offers the possibility to more directly control the availability of water and nutrients, and avoid temporal shortages. The higher production of stem could be due to the elevated EC which was observed in cocopeat as was shown in lettuce where higher EC resulted in more nitrate and total reduced-N and lettuce grew faster (Gent, 2003). Meanwhile, T9 indicated as the lowest of dry weight of leaf (17.36g), stem (18.17g), and root (7.24g) as refer in Table 5.5 due to high salinity (EC). According to Qiu et al. (2018), an increase in the EC apparently led to a significant decrease in the dry weight of roots, stems, and leaves of the hot peppers especially when the EC was high. A similar response in the high EC was reported by Lycoskoufis et al. (2005) which salinity stress (recirculating the nutrient solution) reduced the dry weight in the stems and roots in the pepper plants by 50% compared with that when standard nutrition was used. Azuma et al. (2010) proved that the dry weight of the whole hot pepper plant in the high EC reduced by 29% relative to the control (a nutrient solution). Niu et al. (2010) also found that the reduction of the dry weight of shoots in high EC (4.1 $dS \cdot m^{-1}$) ranged from 22% to 92% for eight chili peppers (five cultivars of *Capsicum annuum* L., two cultivars of *Capsicum chinense*, and one accession of C. annuum). The analysis of variance shown that the effect of different growth media was significant difference ($P \leq 0.05$) on root:shoot ratio effect on dry weight of plants. It indicated that increased application rate of CCD increased the fresh weight and dry weight per plant. Moreover, Awang et al. (2009) also reported that the increased of cocopeat rate in growth media resultant in high dry weight of stem, leaves and root after found the highest of stem, leaves and root dry weight of *Celosia cristata* grown in 100% cocopeat and 70 cocopeat: 30 burnt rice hulls compared to other treatments.

Table 5.5 : The effect of different growth media on leaf, stem, root dry weight, and root: shoot ratio

Growth media	Dry Matter Production		
	Leaf (g)	Stem (g)	Root (g)
T1	54.37±2.87[a]	60.03±1.29[a]	23.25±0.82[a]
T2	25.54±1.50[d]	22.08±1.18[cd]	12.83±0.97[b]
T3	34.21±0.75[c]	22.16±1.32[cd]	13.57±0.40[b]
T4	35.71±0.57[c]	23.37±0.86[c]	12.05±0.38[b]
T5	42.78±2.52[b]	41.33±0.71[b]	22.23±1.69[a]
T6	24.25±0.88[d]	21.26±1.89[cd]	11.25±0.99[b]
T7	38.50±2.42[bc]	39.18±2.82[b]	21.62±0.94[a]
T8	28.83±0.92[d]	20.42±0.95[cd]	11.02±0.89[b]
T9	17.36±1.01[e]	18.17±1.15[d]	7.24±0.12[c]
HSD (P<0.05)	368.74***	587.96***	101.13***

Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). * and *** significantly different at P≤0.05, and 0.001 respectively and NS= not significant. Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

5.4.5 Nutrient Content of Fruit

The analysis of variance of nutrient content of harvested fruit showed significant (P≤0.05) affected by different growth media when applied the fertilizer in field by fertigation system (Appendix I-h). The nutrient content of harvested fruit that have been analysed in this experiment were C, N, S, P, K, Ca, Fe, Mg, Zn, Al, Mn, Na and C:N ratio. Table 5.6 represented the nutrient content of harvested fruit in different growth media when applied the fertilizer in field. Table 5.6 shown that T8 contained highest C content in harvested fruit with 36.70%, meanwhile T2 contained lowest C content in harvested fruit with 23.15% compared to other growth media. Wijitkosum and Sriburi (2018) found that carbonstorage in maize biomass was increased when the biochar was added with the fertilizer. The high level of biochar with the addition of fertilizer resulted in a significantly higher amount of carbon storage than the addition of fertilizer alone. Adding the appropriate amount of biochar into growth media promotes plant growth (Wijitkosum and Kallayasiri, 2015; Sriburi and Wijitkosum, 2016; Wijitkosum, 2017). Moreover, the presence ofbiochar in growth media promotes the plant growth and productivity because biochar is organic carbon that cannot be easily digested by soil microorganisms Lehmann et al.,2006, Glaser et al.,2002; Kim et al.,2012; Singh 2010). Biochar with the fertilizer was applied tohelp restore the soluble nutrients and reduce nutrients leaching from growth media (Lehmann et al.,2011; Bridgwater,2006; Liang et al.,2010; Glaser et al.,2015, Chan et al.,2007). The highest Mg (51.49mg/l) and Zn (0.70mg/l) content in harvested fruit grownin T4 compared to other growth media. Meanwhile, T5 contained the highest K (30.92mg/l) and Ca (27.23mg/l) content in harvested fruit compared to other growth media. Moreover,T1 resultant in highest N (0.40%) and S (0.08%) content in harvested fruit.

Awang et al.(2009) reported that combinations of cocopeat based growing media have the high nutrient uptake of selected macronutrients contents such as N, P, K, Ca and Mg on plant nutrient contents (%) of *Celosia cristata* by improved nutrient uptake efficiency in optimum pH and salinity (Argo and Biernbaum, 1996; Altland and Buamscha, 2008; Havlin et al., 2014). Contrast with T9 that contained lowest N (0.17%) P (9.00mg/l), and S (0.009%) content in harvested fruit compared to other growth media, and resultant in high C:N ratio in harvested fruit with 204.78. Furthermore, T2 demonstrated as the highest Fe, Al, Mn, Na in harvested fruit with 9.93mg/l, 5.44mg/l, 0.81mg/l, and 11.06mg/l. According to Table 5.6, the highest P content in harvested fruit grown in T6 with 20.10mg/l but contained the lowest K content (10.34mg/l) in harvested fruit. According to Huang et al. (2017), the presence of high EC leads to excessive accumulation of mineral nutrients and some salt ions such as iron Fe, Na, and Cl to accumulate in plant. Moreover, the high EC also caused decreasing of nutrient concentrations of K, Ca and Mg due to decreased ion activity in the soil solution as a result of both increased soil adsorption and mineral precipitation and this caused their concentrations to decrease in plant organ (Huang et al.,2017).

This luxury consumption of ions is essential for the plants to compensate for the increased outside osmotic pressure but is responsible for growth retardation. However, the excessive uptake of certain ions resultant in reduced uptake of some essential plant nutrients causing nutrient imbalances and deficiencies, as well as compensate for the decreased uptake by plants resulting from the antagonistic effect of excess uptake of certain ions (Abrol et al.,1988). Results of several studies tend to show that deficiencies of the elements K and Ca appear to play an important role in the observed growth depressions in saline soils (Finck, 1977). In addition, the concentrations of some nutrients such as P and Cu were little influenced by EC. All growth media contained less than or equal to 0.01mg/l of other nutrient content in harvested fruit by refer to Table 5.6.

Table 5.6 : The nutrient content of harvested fruit in different growth media by applied the fertilizer in fertigation system. Mean with different letters are significantly differentat at P≤0.05 using Tukey's Studentized Range (HSD)

Growth media							Element							
	C (%)	N (%)	C/N	S (%)	P (mg/l)	K (mg/l)	Ca (mg/l)	Fe (mg/l)	Mg (mg/l)	Zn (mg/l)	Al (mg/l)	Mn (mg/l)	Na (mg/l)	Ot her
T1	30.43±0	0.40±0.	76.09±	0.08±0.	18.30±	18.80±	26.03±	2.34±	16.81±	0.16±	0.91±	0.08±	9.91±0.	≤0.
	.040**d**	006**a**	0.98**h**	004**a**	0.020**b**	0.15**f**	0.044**b**	0.001**d**	0.030**f**	0.002**g**	0.003**e**	0.010**g**	002**d**	1
T2	23.15±0	0.26±0.	88.93±	0.04±0.	12.50±	30.59±	21.46±	9.93±	19.51±	0.19±	5.44±	0.81±	11.06	≤0.
	.020**i**	003**d**	0.92**g**	003**d**	0.010**e**	0.11**c**	0.010**f**	0.002**a**	0.010**d**	0.003**e**	0.002**a**	0.001**a**	±0.010**a**	1
T3	32.39±0	0.20±0.	161.69	0.02±0.	14.90±	15.54±	17.06±	1.74±	9.895±	0.13±	0.38±	0.47±	9.78±0.	≤0.
	.052**c**	002**g**	±1.52**b**	003**f**	0.050**c**	0.052**g**	0.050**i**	0.002**f**	0.002**i**	0.001**h**	0.006**h**	0.000**d**	040**e**	1
T4	27.33±0	0.38±0.	71.86±	0.05±0.	12.20±	21.37±	24.46±	4.86±	51.49±	0.70±	0.73±	0.002	8.98±0.	≤0.
	.040^{f}	003^{b}	0.65^{i}	002^{c}	0.020^{f}	0.085^{e}	0.020^{d}	0.003^{c}	0.017^{a}	0.003^{a}	0.005^{f}	±0.00	010^{g}	1
T5	26.14	0.28±0.	93.36±	0.06±0.	13.00±	30.92±	27.23±	1.65±	22.19±	0.18±	2.09±	0.60±	10.24±	≤0.
	±0.020**g**	002**c**	0.58**f**	004**b**	0.030**d**	0.11**b**	0.030**a**	0.002**g**	0.017**c**	0.001**f**	0.004**c**	0.002**c**	0.020**c**	1
T6	25.06±0	0.25±0.	100.25	0.03±0.	20.10±	10.34±	17.18±	1.39±	17.12±	0.55±	4.70±	0.43±	10.95±	≤0.
	.020**h**	003**e**	±1.37**e**	002**e**	0.020**a**	0.10**h**	0.020**h**	0.005**h**	0.010**e**	0.001**b**	0.004**b**	0.005**e**	0.001**b**	1
T7	28.62±0	0.23±0.	124.44	0.03±0.	10.30±	15.61±	19.97±	0.98±	15.84±	0.16±	0.64±	0.61±	9.35±0.	≤0.
	.017**e**	002**f**	±1.02**d**	002**e**	0.017**g**	0.040**g**	0.020**g**	0.001**i**	0.017**h**	0.002**g**	0.002**g**	0.002**b**	010**f**	1
T8	36.70±0	0.28±0.	131.08	0.06±0.	13.00±	31.85±	25.23±	1.76±	49.55±	0.20±	0.91±	0.01±	8.55±0.	≤0.
	.030**a**	003**c**	±1.27**c**	003**b**	0.040**d**	0.082**a**	0.020**c**	0.003**e**	0.020**b**	0.002**d**	0.004**e**	0.001**h**	017**h**	1
T9	34.81±0	0.17±0.	204.78	0.009±	9.00±0.	23.32±	23.74±	7.19±	16.22±	0.25±	1.01±	0.15±	6.11±0.	≤0.
	.040**b**	002**h**	±1.90**a**	0.001**g**	020**h**	0.15**d**	0.010**e**	0.001**b**	0.010**g**	0.001**c**	0.002**d**	0.004**f**	010**i**	1
HSD	62.24**	0.017*	5735.6	0.0015	38.21*	180.47	42.39*	29.45	35.65*	0.12*	5.32*	0.13*	6.75**	-
(P<0.05)	*	**	0***	***	**	***	**	***	**	**	**	**	*	

Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB.

5.5 Conclusion

T1 (100% coconut coir dust) was determine as best growth media that enhance the organic matter chemical properties, plant growth parameter, and yield productions of *Capsicum annuum L. Var. Kulai* after planting and applied the standard rate of chemical fertilizer for chilli plant by fertigation system. This experiment indicated that the application of 100% cocopeat improve plant height, stem diameter, total leaf area, chlorophyll content, short day to initiate the flowering, number and weight of yields, fruit nutrient content, root volume, and total dry weight of *Capsicum annuum L. Var. Kulai* because coconut coir dust (CCD) or cocopeat has good horticultural properties such as high moisture retention capacity, available nutrient content, infiltration rate, and total porosity

Moreover, the application of 100% coconut coir dust as growth media in this experiment reached the optimum balance condition for plant growth and development by contained high in pH, electrical conductivity, cation-exchangeable capacity, exchangeable cations Ca, Mg and Na, as well as high in macronutrient and micronutrient (except Zn and Mn content) after planting and fertilizer application. However, the high rate of coconut shell ash and palm kernel shell biochar can suppress the plant growth and production in application of fertilizer due to high salinity by excess fertilizer rate in growth media that affect the pH and CEC to become decrease.Excess fertilizer application would result in low water availability to plant due to high osmotic conditions in growth media, thus it will stunt the plant growth and reduce the crop's yield.Therefore, the other experiment related on salinity need to be conducted on the field by using fertigation system to investigate the effect of different fertilizer rate (salinity) toward the chemical properties of growth media and plant growth performances.

CHAPTER 6

THE BENEFICIAL USE OF GROWTH MEDIA MIXTURES IN MINIMIZING FERTILIZER CONSUMPTION ON *CAPSICUM ANNUUM* IN FERTIGATION SYSTEM

6.1 Introduction

This analysis was conducted at the field (shelter house) to indicate the beneficial use of growth media mixtures in minimizing fertilizer consumption on *Capsicum annuum* in fertigation system and evaluate the cost-benefit of different growth media mixtures under fertigation system. The physio-chemical properties, water and nutrient retention were analysis (refer to previous chapter). Chilli (*Capsicum annuum Var* Kulai) was chosen as crop sample in this experiment to investigate the effect of different rate of growth media on plant growth performance. The fertigation system was set up on January before start the experiment. The plant was irrigated by drip irrigation twice daily. The study was involving the setup of fertigation system, preparation of the soilless media into polybag, field layout arrangement, sowing and transplant the seedling, weeding and insect control, data collection, harvesting period, destruct the plant part, and laboratory analysis. Then, a structure of costs and revenue of recommended growth media applied with three different fertilizer rates were tabulated and the benefit cost ratio was calculated between the net benefit and total costs. The growth media were arranged by Split-plot in randomized complete block design (RCBD) arrangement with three replications.

6.2 Materials and Methods

6.2.1 Selection of Experimental Site, Planting Materials and Design

This study was conducted at Shelter House 4 and 5 at Agrotechnology Farm, University Agriculture Park, Universiti Putra Malaysia (UPM), Serdang, Selangor. The roof of shelter house was covered by using 0.04mm silver shine (80 meter with 4 feet of width) and mean daily temperature was 29°C to 40°C with relative humidity ranged 60% to 65%. The tabulation of annual rainfall was 2369 mm and average monthly temperature was 26.9 °C. Meanwhile the planting material used in this study is *Capsicum annuum L. Var. Kulai*. The seed was 461 Sakata Hot Pepper F1 Hybrid from Pewaris Bumi Hijau Sdn. Bhd,Telok Panglima Garang,Selangor. The growth media were arranged by Split-plot in randomized complete block design (RCBD) arrangement with four replications. The experimental lay out was presented in Appendix F.

6.2.2 Soilless Growth Media and Method of Application

The preparation of soilless growth media as shown in Table 3.1 using the method mentioned in section 3.1.1. The growth media were arranged by Split-plot in randomized complete block design (RCBD) arrangement with four replications and polybag distance at 2 m x 2 m. The plants were established for a period of four months and throughout the study period, the data on soilless media properties, growth and physiological status were taken as an indicator to determine the effect of different rate of growth media on *Capsicum annuum* growth performance in fertigation system.

6.2.3 Media Analysis

6.2.3.1 pH and Electrical Conductivity

The soil pH and electrical conductivity were measured using the method mentioned in section 3.2.5.

6.2.3.2 Total Organic Carbon, Nitrogen, and Sulfur

The total organic carbon, nitrogen and sulfur were determined by using the CNS TruMac Determinators (LECO) as mention in section 3.2.6.

6.2.3.3 Cation Exchangeable Capacity (CEC) and Exchangeable Cations

The CEC and exchangeable cations (K^+, Ca^{2+}, Mg^{2+}, and Na^+) was determined using 1M NH4OAc buffered at pH 7.0 as extractant by using leaching method as mentioned in section 3.2.7.

6.2.3.4 Nutrient Content

The nutrient contents in growth media were determined by using the method as referred in section 3.2.8.

6.2.4 Plant Growth Characteristics

6.2.4.1 Sowing and Transplant the Seedling

The sowing and transplant the seedling were using the method mentioned in section 3.3.1

6.2.4.2 Water and Fertilizer Application

The application of water and three different rates of chemical fertilizer (100% of fertilizer rate, 75% of fertilizer rate, and 50% of fertilizer rate) were irrigated using the method mentioned in section 3.3.2 to the plant and provide the nutrient essential for plant growth. Total amount of nutrient solution and EC level in different rates of chemical fertilizer were presented in Appendix C.

6.2.4.3 Weed, pest and disease control

The weed, pest and disease control were explained in section 3.3.3.

6.2.5 Measurement of Vegetative Growth

6.2.5.1 Plant Height

The height of the plant was measured using the method mentioned in section 3.4.1.

6.2.5.2 Stem Diameter

The stem diameter of the plant was measured using the method mentioned in section 3.4.2.

6.2.5.3 Days of Flowering

The data pertaining to the number of days to initiation of flowering, 50% of flowering, and initiation of fruit set were determined by using the method as referred in section 3.4.3

6.2.5.4 Number and Weight of Fruit (Yield)

Number and weight of harvested fruit were determined by using the method as referred in section 3.4.4

6.2.5.5 Total Leaf Area (TLA)

Total leaf area was determined using the method explained in section 3.4.5.

6.2.5.6 Chlorophyll Content

Leaf chlorophyll concentration was determined by using the method as referred in section 3.4.6.

6.2.6 Root Size and Distribution

6.2.6.1 Root Length, Root Diameter, Root Surface Area and Root Volume

The root length, root diameter, root surface area, and root volume were measured by using the method mentioned in section 3.5.1.

6.2.7 Dry Matter Production

6.2.7.1 Root Dry Weight, Shoot Dry Weight and Root to Shoot Ratio

Dry weight of the leaves, stem and roots were obtained by using the method mentioned in section 3.6.1.

6.2.8 Determination of Fruit Nutrient Content

Nutrient content in harvested fruit were determined and analyzed using the method mentioned in section 3.7.

6.3 Cost-Benefit

The cost–benefit analysis determines the revenue created by an investment project exceeds its costs. A structure of costs and revenue for 1,000 polybeg of recommended growth media applied with three different fertilizer rates along 4 months DAT were utilized. The costs were classified into fixed and variable costs (Cámara-Zapata et al., 2019). The fixed costs did not depend on production. Whereas the variable costs have a direct relationship with the final production. The fixed costs are classified into overhead costs and operational fixed costs. The overhead costs are projected as a multi-year cost be used during the length of the experiment such as land rental. The fixed operational costs did not depend directly on the final production such as the input cost (growth media, chilli seed, fertilization, insecticides and weedicide) and labour and operation cost. The cost of the labour and operation cost refers to the amount paid to third parties for providing a service and activity performed at specific period such as site preparation, planting, weeding, praying insecticide, harvesting, electricity and water cost. The revenue was obtained from first harvesting production and the official farm prices. The prices provided by agricultural cooperatives were used. The net benefit was obtained as the difference between the total income and total costs (Cámara-Zapata et al., 2019). Thus, the benefit cost ratio was determined between the net benefit and total costs.

6.4 Statistical Analysis

All the data collected during the study were recorded and analysed using analysis of variance (ANOVA) by Statistical Analysis System (SAS 9.4) for Split-plot in randomized complete block design (RCBD) with three replications to determine the significance difference between the growth media means. Differences between means separated using Tukey's Studentized Range (HSD) at $P \leq 0.05$ level.

6.5 Results and Discussion

6.5.1 Soilless Media Analysis

6.5.1.1 pH Value

From Appendix J-a, analysis of variance shown the effect of different growth media in three different fertilizer rates was highly significant ($P \leq 0.05$) on pH value. Moreover, the pH in all growth media was significantly ($P \leq 0.05$) affected by three different fertilizer rates. The different fertilizer rates consist of 100% of fertilizer rate, 75% of fertilizer rate, and 50% of fertilizer rate. Figure 6.1 illustrated that all growth media resulted in increased trend of pH value except for pH value in T1, T4, and T8 when reduced the fertilizer rates. According to Figure 6.1, the pH value in T2 shown the upward trend from 6 to 6.31 when reduced the fertilizer rates. T2 also demonstrated as the highest pH value in 50% fertilizer rate, followed by T5 (6.21) compared to other growth media.

Meanwhile, the pH value in T1 declined from 5.58 to 4.85 (acidic) when reduced the fertilizer rates, thus T1 contained the lowest pH values of 4.85 (acidic) in 50% of fertilizer rate compared to other growth media. Neina (2019) reported that the decreased of pH cause by decreased of exchangeable cations (K^+, Ca^{2+}, Mg^{2+}, and Na^+) and replaced by H^+ and Al^{3+} ions in growth media. According to McBratney (2006), the increased of total organic carbon and total nitrogen in growth media also caused the pH declined due to the dissolution of CO2 in water producing carbonic acid, which dissociates and releases H^+ ions and nitrification of ammonium (NH_4^+) to nitrate NO3- produces H+ ions in growth media.

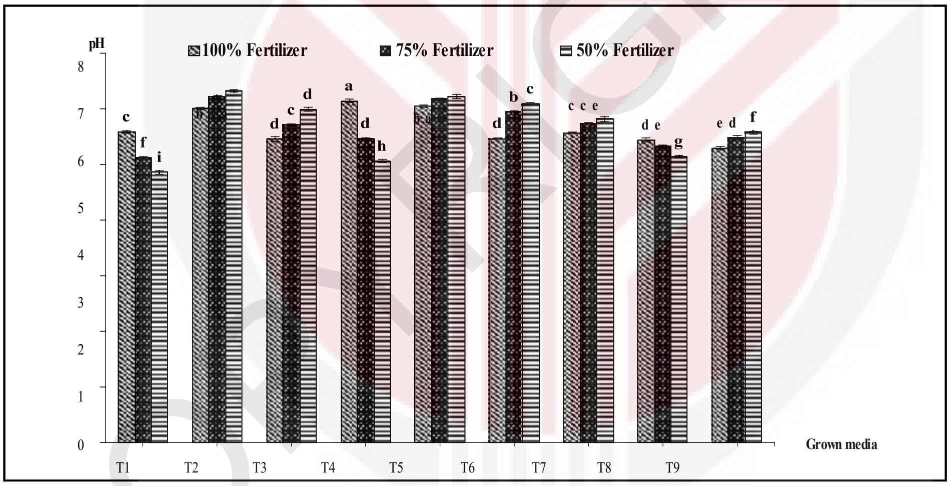


Figure 6.1 : The pH value of different growth media in different fertilizer rates. Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD : 1PKSB, T9=1CCD :1PKSB

6.5.1.2 Electrical Conductivity

The analysis of variance justified the effect of different treatment in three different fertilizer rates was highly significant ($P \leq 0.05$) on electrical conductivity (Appendix J-b). Moreover, the electrical conductivity (EC) in all growth media was significantly ($P \leq 0.05$) affected by three different fertilizer rates. According to Figure 6.2, all growth media resulted in decreased trend of EC when reduced the fertilizer rates. Figure 6.2 shown T2 demonstrated as the highest EC (1.03dS/m) in 50% fertilizer rate, followed by T9 (0.95dS/m) compared to other growth media. In contrast, the EC in T1, T4 and T8 contained the lower EC of 0.22dS/m, 0.35dS/m and 0.36dS/m in 50% of fertilizer rate compared to other growth media. Yahya (2009) reported that the acceptable range of EC in good soilless media should be between 0.4 dS/m to 1.5 dS/m. Singh and Bruce (2016) also stated that the optimum EC for *Capsicum annuum* L. is between 0.8 dS/m to 1.8 dS/m. According to Figure 6.2, all growth media were maintained in moderate and acceptable range of EC ofa good soilless media (0.4 dS/m to 1.5 dS/m) although resulted in decreased trend of EC when reduced the fertilizer rates. However, T1(0.22dS/m), T4(0.35dS/m) and T8 (0.36dS/m) resulted in below the acceptable range of EC of a good soilless media and optimum EC range for *Capsicum annuum* L in 50% of fertilizer rate compared to other growth media. This indicated that T1, T4 and T8 contained a low level of nutrient concentration in growth media cause the *Capsicum annuum* L. required somesupplementation of fertilizer nutrients by adding the fertilizer in growth media (Othaman et al.,2020). According to Samarakoon (2014), EC that too low indicates insufficient nutrition for the plant and this will cause some nutrient deficiencies and slow down or stunted the plant growth. Suhandy (2014) also reported that yield reduction occur that caused by reduction in the average fruit weight at low solution electrical conductivity (ECs). Meanwhile, low EC results in slow growing plants with disorders such as leaf yellowing, whereas excessively high EC can lead to toxicity and poor plant growth.

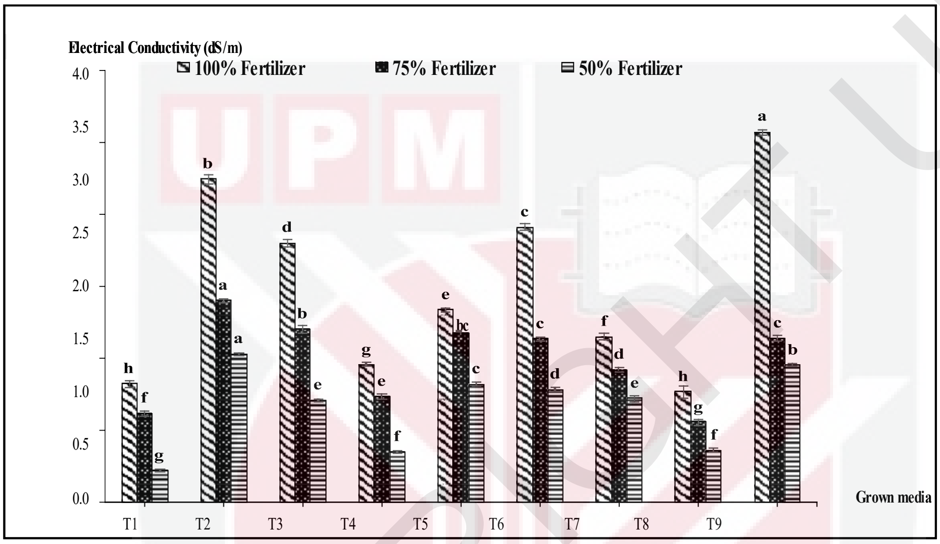


Figure 6.2 : The electrical conductivity of different growth media in three different fertilizer rates. Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKS

6.5.1.3 Cation Exchange Capacity and Soil Exchangeable Bases (K, Ca, Mg, and Na)

According to Appendix J-c, the analysis of variance proven that the effect of different growth media in three different fertilizer rates was highly significant (P≤0.05) on cation exchange capacity (CEC). Moreover, the cation exchange capacity (CEC) in all growth media was significantly (P≤0.05) affected by three different fertilizer rates. Figure 6.3 represented the CEC in all growth media shown in upward trend except for CEC in T1, T4, and T8 when reduced the fertilizer rates. From Appendix J-d, the exchangeable cations (K^{+}, Ca^{2+}, Mg^{2+} and Na^{+}) in three different fertilizer rates were significantly ($P \leq 0.05$) affected by different growth media. Meanwhile, the analysis of variance (ANOVA) proven that three different fertilizer rates were highly significant ($P \leq 0.05$) on exchangeable cations (K^{+}, Ca^{2+}, Mg^{2+} and Na^{+}) in different growth media as refer to Appendix J-d. Table 6.1 represented the exchangeable cations (K^{+}, Ca^{2+} and Mg^{2+}) on different growth media in three different fertilizer rates. The exchangeable cations (K^{+}, Ca^{2+}, Mg^{2+} and Na^{+}) in all growth media shown in upward trend except for T1, T4, and T8 when reduced the fertilizer rates. Figure 6.3 illustrated that the CEC in T2 rose from 8.64cmolc/kg to 17.93cmolc/kg when reduced the fertilizer rates due to increase the exchangeable cations K^{+} (1.09cmolc/kg), Ca^{2+}(22.19cmolc/kg), Mg^{2+}(3.02cmolc/kg) and Na^{+}(0.36cmolc/kg) in 50% fertilizer rate.

Moreover, T2 contained the highest CEC of 17.93cmolc/kg in 50% fertilizer rate, followed by T5 (14.64cmolc/kg) compared to other growth media. In contrast with T1 contained the lowest exchangeable cations K^{+} of 0.17cmolc/kg in 50% offertilizer rate, meanwhile the lowest of exchangeable cation Ca^{2+} was in T4 (9.18cmolc/kg)in 50% of fertilizer rate compared to other growth media. Table 6.1 also shown that T1 and T4 contained the lowest of exchangeable cations Mg^{2+} of 0.59cmolc/kg in 50% of fertilizerrate. Meanwhile, T8 resulted in lowest of exchangeable cation Na^{+} with 0.011cmolc/kg in50% of fertilizer rate compared to other growth media. Therefore, T1, T4 and T8 shown the decreased trend of CEC from

15.64cmolc/kg to 6.45cmolc/kg, 8.71cmolc/kg to 7.93cmolc/kg, and 12.4 cmolc/kg to 8.21 cmolc/kg in decreased of fertilizer rates. Rengasamy and Churchman (1999) reported that pH and organic matter content influenced the CEC in growth media. The increased of CEC in growth media occur due to high in negative charges in organic matter that retained and held positively charged ions such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}), sodium (Na^{+}), thus reduced nutrient loss by leaching (Astera,2010). According to Hailegnaw et al.,(2019) the increasing of pH indicated the low of H^{+} and Al^{3+} ions concentration in organic matter and greater the capacity (negative charge) of the growth media to hold more cations.

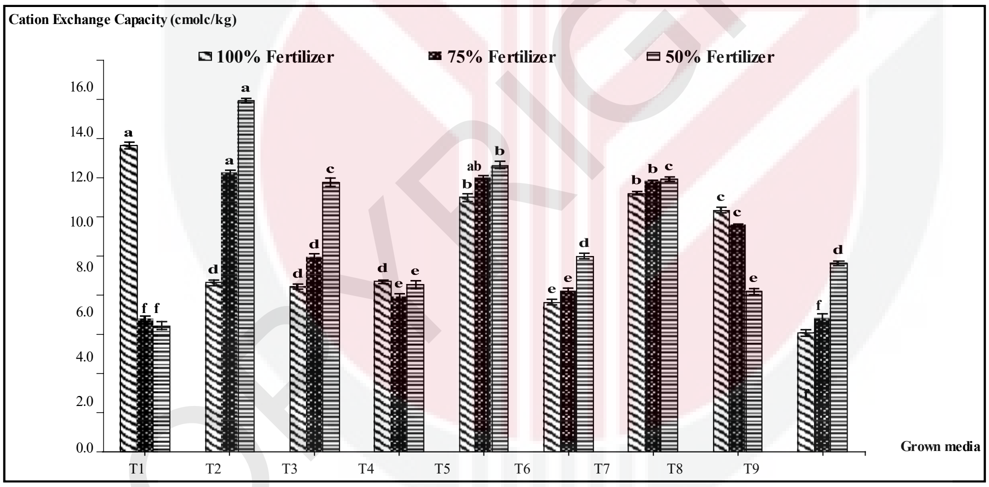


Figure 6.3 : The Cation Exchange Capacity (CEC) of different growth media in three different fertilizer rates. Means with different letters are significantly different at P P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

Table 6.1 : The exchangeable cations K, Ca, Mg, and Na of different growth media in three different fertilizer rates

Growth media	Fertilizer rate	Exchangeable Bases (cmolc/kg)			
		K+	Ca2+	Mg2+	Na+
T1	100% of fertilizer	0.67±0.002[c]	11.10±0.08[c]	1.20±0.005[b]	0.084±0.001[e]
	75% of fertilizer	0.58±0.008[d]	10.95±0.18[e]	1.24±0.005[d]	0.049±0.001[f]
	50% of fertilizer	0.17±0.001[h]	10.10±0.10[h]	0.59±0.002[g]	0.029±0.002[h]
T2	100% of fertilizer	0.35±0.002[e]	12.94±0.02[b]	1.20±0.005[b]	0.14±0.002[b]
	75% of fertilizer	1.33±0.002[a]	14.93±0.07[a]	2.70±0.079[a]	0.38±0.002[b]
	50% of fertilizer	1.09±0.002[b]	22.19±0.02[a]	3.02±0.006[a]	0.36±0.002[b]
T3	100% of fertilizer	0.31±0.001[f]	7.90±0.13[g]	0.87±0.007[e]	0.040±0.001[g]
	75% of fertilizer	0.48±0.002[f]	8.50±0.02[g]	1.51±0.007[b]	0.14±0.002[d]
	50% of fertilizer	0.86±0.004[c]	11.80±0.01[e]	1.31±0.031[d]	0.17±0.004[e]
T4	100% of fertilizer	2.92±0.009[a]	9.99±0.02[ef]	0.83±0.010[f]	0.72±0.003[a]
	75% of fertilizer	1.06±0.001[b]	10.24±0.05[f]	0.77±0.006[f]	0.60±0.003[a]
	50% of fertilizer	0.60±0.001[e]	9.18±0.07[i]	0.59±0.002[g]	0.16±0.001[f]
T5	100% of fertilizer	0.44±0.001[d]	13.23±0.03[a]	1.11±0.006[c]	0.13±0.001[c]
	75% of fertilizer	0.50±0.012[e]	13.25±0.04[b]	1.37±0.007[c]	0.071±0.001[e]
	50% of fertilizer	0.64±0.004[d]	19.37±0.03[b]	1.94±0.007[c]	0.42±0.003[a]
T6	100% of fertilizer	0.43±0.003[d]	10.24±0.02[d]	0.88±0.008[e]	0.050±0.001[f]
	75% of fertilizer	0.60±0.003[d]	10.32±0.01[f]	1.14±0.004[e]	0.14±0.001[d]
	50% of fertilizer	0.58±0.002[f]	14.36±0.01[c]	1.22±0.006[e]	0.34±0.003[c]
T7	100% of fertilizer	0.22±0.002[g]	10.14±0.03[de]	0.93±0.008[d]	0.12±0.004[d]
	75% of fertilizer	2.43±0.006[f]	12.52±0.02[c]	1.29±0.013[d]	0.15±0.002[c]
	50% of fertilizer	0.47±0.009[a]	12.93±0.03[d]	2.16±0.019[b]	0.33±0.005[d]
T8	100% of fertilizer	1.62±0.005[b]	13.11±0.02[a]	1.63±0.008[a]	0.13±0.001[c]
	75% of fertilizer	0.95±0.001[c]	12.51±0.02[c]	1.53±0.007[b]	0.075±0.002[e]
	50% of fertilizer	0.22±0.002[g]	10.84±0.04[g]	0.66±0.013[f]	0.011±0.001[i]
T9	100% of fertilizer	0.02±0.001[h]	9.93±0.06[f]	0.55±0.002[g]	0.008±0.001[h]
	75% of fertilizer	0.38±0.002[g]	11.18±0.04[d]	1.27±0.008[d]	0.027±0.001[g]
	50% of fertilizer	0.64±0.001[d]	11.37±0.05[f]	1.27±0.017[d]	0.076±0.001[g]

Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB.

6.5.1.4 Nutrient Content

From Appendix J-e to Appendix J-g, the analysis of variance of nutrient content and C:N ratio in organic matter showed significant ($P \leq 0.05$) affected by different growth media. Meanwhile, Appendix J-e to Appendix J-g also justify that the concentration of C, N, S, P, K, Ca, Fe, Mg, Zn, Al, Mn, Na and C:N ratio in all growth media showed significant ($P \leq 0.05$) differences by application of different fertilizer rates. Table 6.2 shown the nutrient content in different growth media when applied 100%, 75%, and 50% of fertilizer rates. According to Table 6.2, the concentration of N (%) and Na were decreased in all growth media when reduced the fertilizer rates from 100% to 50% due to decrease in salinity in growth media. Over fertilization contribute to soil salinization and increase the negative effects of soil salinity on plant performance (Villa-Castorena et al., 2003). Salinization by irrigation water is a process whereby soluble salts from the irrigation water accumulate in growth media due to inadequate leaching, high water tables and/or high evaporation rates. The salinity in growth media affects plants directly through osmotic effects, which limit the ability of the plants to absorb water from growth media. Specific ion effects and changes in physical and chemical properties of growth media can have long-term detrimental effects on crop production (Keren, 2000). Activity of nutrients in growth media solution is affected by high concentrations of salt ions, usually Na and Cl that resultant in a nutritional disorder in plants (Grieve and Grattan,2012).

While application of high fertilizers rate could increase the salinity of soil solution. Esmaili et al. (2008) indicated that in high salinities, application of fertilizers in higher than ordinary rate may cause more salinity and osmotic pressure and may decrease water and nutrients uptake and decrease the growth. In other words, nutrients deficiency can be the main limitation for plant growth under low salinity. However, the high salinity limits growth more than nutrient deficiency. N deficiency also can result from N removal by plant from the growth media after the harvest of biomass and absence of fertilizers, thus N loss from erosion, runoff, and leaching, addition of plant materials with high C:N ratio can also accelerate the deficiency due to immobilization of N in growth media. The salt-affected growth media contain excessive concentrations of either soluble salts or exchangeable sodiumor both due to inadequate leaching of base forming cations.

The major soluble minera lsalts are the cations: sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and the anions: chloride (Cl^-), sulfate ($SO^{2}-4SO4^{2-}$), bicarbonate ($HCO-3HCO^{3-}$), carbonate ($CO2-3CO3^{2-}$), and nitrate ($NO-3NO3^{-}$). Hyper-saline soil water may also contain boron (B), selenium (Se), strontium (Sr), lithium (Li), silica (Si), rubidium (Rb), fluorine (F), molybdenum (Mo), manganese (Mn), barium (Ba), and aluminum (Al), some of which can be toxic to plants and animals (Tanji, 2002). The enhanced Na^+ absorption in sodic soils or growth media reduces K^+ absorption which adversely affects the enzymatic activities involved in metabolic processes like photosynthesis and protein synthesis (Hauser and Horie, 2010). The increased Na^+ concentration in different plant parts (root, shoot, and grains) in control plants might be associated with the increased Na^+ ions in growth media and rooting medium (Álvarez and Sánchez- Blanco,2015). N2 is the most abundant gas in Earth's atmosphere and can be found in amino acids and proteins and many organic compounds are derived from the nitrogen fixation process (Hoffman et al.,2014). Nitrogen is an essential constituent of proteins, nucleic acids, some carbohydrates, lipids, and many metabolic intermediates involved in synthesis and transfer of energy molecules (Yang et al.,2013). Lira et al.(2019) obtained for the extraction of N (130 and 127.352 kg ha^{-1}, respectively) were higher than the 120 kg ha^{-1} N that was incorporated into growth media via fertilizer. In addition, the potential for NO3 leaching may increase where moderate to high amounts of salts are present in growth media because plants under salt stress cannot absorb and or utilize the applied N as efficiently as the plants not subjected to salt stress (Ward et al., 1986; Pessarakli and Tucker 1988; Bowman et al., 2006). Inefficient usage of water and fertilizers has led to an increase in nitrate (NO3) levels. Nitrogen (N2) is an essential element for the support of all forms of life. Table 6.2 also illustrated that C content in all growth media rose in reduced the fertilizer rates except T1, T4, T7 and T8. Thus, the increased of C:N ratio occur in all growth media when decreased of fertilizer rates due to high C content than N content (%). Lehmann and Joseph (2015) reported that the increase in SOC following the addition of biochar to growth media has been reported to raise the C:N ratio, which in turn could affect N mineralization.

This corroborated in previous studies reported by Kasozi et al. (2010) and Bruun et al. (2012) who attributed it to the increased release and microbial mineralization of organic carbon compounds entrained in the porous structure of biochar. The positive increase in SOC and macronutrients upon soil amendment with digestate-enriched biochar materials indicates that coupling anaerobic digestion and pyrolysis could be an important step in improving and maintaining long term fertility (Backer et al.,2016). Wijitkosum and Sriburi (2018) found that carbon storage in maize biomass wasincreased depending on the amount biochar added into the soil, especially when the biochar was added with the fertilizer. However, the opposite result found in increased of S content in T1, T4, and T8 when reduced of fertilizer rates compared to other growth media. Furthermore, Table 6.2 also shown that T1 and T4 incurred the decreased of P, K, Ca, and Mg, and increased of Fe, Zn, Al and Mn when decreased of fertilizer rates. Moreover, the concentration of P, Fe, Zn, Al and Mn rose in T8 when decreased of fertilizer rates. Meanwhile, the declined of P, K, Fe, Al, and Mn occurred in T2 when decreased of fertilizer rates except for Ca, Mg, and Zn contents. T3, T5, T6, T7, and T9 resultant in decreased of P, Zn, Al, and Mn content and increased of K, Ca, and Mg when reduced of fertilizer rates as refer to Table 6.2. Skwierawska et al. (2012) indicated a varied impact of sulfur on nutrient mobility in soils. Incorporating elemental sulfur (S) is the most effective way to lower pH level in growth media because the sulfur oxidizes to sulfuric acid, thus lowering the pH (Tabak et al.,2020). High sulfur rates tended to result in high concentration of sulphates in growth media as compared to the low fertilization doses (Skwierawska et al.,1997). Gurmessa (2021) reported that pH affects nutrient availability, water uptake, biological activity and solubility of aluminum and iron ions, acidification is a significant indirect yield reducing factor. Similar results were presented by Zhi-Hui et al. (2010), Rahman et al.(2011), Skwierawska et al. (2012) and

Karimizarchi et al. (2016). Castanon et al. (2019) concluded that soil pH was decreased linearly with increasing sulfur doses and content in growth media.

Elemental sulfur oxidized by microbes to produce sulfate (SO_4^{2-}) and H^+ cause a lower pH. Moreover, pH also influenced by both acid and base-forming ions in growth media. Common acid-forming cations (positively charged dissolved ions) are hydrogen (H^+), aluminum (Al^{3+}), and iron (Fe^{2+} or Fe^{3+}), whereas common base-forming cations include calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and sodium (Na^+). An increase in sulfur content in growth media causes increased leaching of base cations and the soil pH is lowered. Metals (Cu, Fe, Mn, Ni, and Zn) are very tightly bound to growth media at high pH and are therefore more available at low pH levels than high pH levels. This can cause potential metal toxicities for crops in acid growth media. Conversely, 'base' cations (Ca, K, Mg) are weakly bound to growth media and are prone to leaching at low pH. Ferrous sulfate ($FeSO_4$) and aluminum sulfate ($Al_2(SO_4)_3$) can also be used to lower pH due to SO_4 and addition of acidic cations (Fe^{2+}, Al^{3+}). The optimal value of pH for the growth and development of many crop ranges from 6 to 7 (Kissel, et al.,2020). Moreover, that application of conventional fertilizers causes formation of strong inorganic acids, and as a resultant in lowers soil pH (Kissel et al.,2020; Mugo et al.,2020). Phosphorus is also affected by pH and its availability in acidic conditions may be reduced by up to 90% (Gurmessa, 2021).

However, nitrogen, potassium and sulfur are less affected by hydrogen ion activity (Goulding, 2016). Slightly acidic conditions favor micro- element availability, and toxic heavy metal concentration increases as pH decreases (Goulding, 2016; Ghimire et al.,2017). Furthermore, excess hydrogen ions in soil solution decrease the availability of basic cations (calcium, potassium, sodium and magnesium). Moreover, the toxic character of aluminum and manganese is revealed and may lead to plant root damage and yield reduction under low pH (Xu et al.,2020). In addition, the high calcium content in growth media indicated the increases of pH level. Most of the agricultural land contains relatively high amounts of $CaCO_3$ and resulting in high pH (Abdou, 2006; El-Tarabily et al., 2006). All growth media contained less than or equal to 0.01mg/l of other nutrient content by refer to Table 6.2.

Table 6.2 : The nutrient content of different growth media in three different fertilizer rates

Growth media	Fertilizer	Element					
		C (%)	N (%)	C/N	S (%)	P(mg/l)	K(mg/l)
T1	100% of fertilizer	51.50 ± 0.030^{i}	0.52 ± 0.003^{c}	99.04 ± 0.52^{g}	0.10 ± 0.004^{f}	8.82 ± 0.003^{b}	207.85 ± 0.036^{a}
	75% of fertilizer	51.13 ± 0.020^{g}	0.48 ± 0.002^{c}	106.52 ± 0.35^{h}	0.08 ± 0.002^{f}	5.76 ± 0.002^{b}	96.20 ± 0.046^{d}
	50% of fertilizer	46.61 ± 0.040^{i}	0.32 ± 0.004^{f}	145.67 ± 1.88^{d}	0.12 ± 0.002^{c}	4.36 ± 0.006^{c}	67.90 ± 0.100^{e}
T2	100% of fertilizer	55.62 ± 0.053^{e}	0.68 ± 0.002^{a}	81.79 ± 0.32^{i}	0.16 ± 0.003^{a}	14.6 ± 0.003^{a}	205 ± 0.111^{b}
	75% of fertilizer	60.44 ± 0.020^{e}	0.57 ± 0.002^{a}	106.04 ± 0.36^{h}	0.15 ± 0.004^{a}	13.50 ± 0.006^{a}	168.45 ± 0.100^{a}
	50% of fertilizer	58.25 ± 0.031^{e}	0.54 ± 0.004^{a}	107.87 ± 0.87^{g}	0.12 ± 0.005^{c}	8.02 ± 0.004^{a}	178.7 ± 0.100^{b}
T3	100% of fertilizer	64.25 ± 0.046^{b}	0.48 ± 0.002^{f}	133.86 ± 0.48^{d}	0.13 ± 0.002^{c}	5.01 ± 0.006^{f}	53.90 ± 0.036^{g}
	75% of fertilizer	70.88 ± 0.040^{a}	0.35 ± 0.003^{f}	202.52 ± 1.45^{a}	0.10 ± 0.002^{d}	3.76 ± 0.004^{e}	68.45 ± 0.020^{f}
	50% of fertilizer	75.06 ± 0.030^{a}	0.35 ± 0.003^{e}	214.47 ± 1.88^{b}	0.08 ± 0.003^{f}	2.16 ± 0.002^{h}	81.69 ± 0.020^{d}
T4	100% of fertilizer	55.03 ± 0.020^{f}	0.50 ± 0.002^{e}	110.06 ± 0.38^{e}	0.12 ± 0.003^{d}	5.83±0.002e	130.75 ± 0.050^{c}
	75% of fertilizer	50.68 ± 0.046^{h}	0.44 ± 0.003^{d}	115.18 ± 0.59^{g}	0.12 ± 0.002^{c}	3.27±0.002f	80.30 ± 0.036^{e}
	50% of fertilizer	47.01 ± 0.012^{h}	0.30 ± 0.004^{g}	156.7 ± 1.93^{c}	0.15 ± 0.004^{a}	3.95 ± 0.003^{d}	36.17 ± 0.030^{h}
T5	100% of fertilizer	53.11 ± 0.017^{g}	0.57 ± 0.002^{b}	93.18 ± 0.31^{h}	0.16±0.002a	7.75 ± 0.003^{d}	92.60 ± 0.035^{e}
	75% of fertilizer	60.51 ± 0.030^{e}	0.51 ± 0.003^{b}	118.65 ± 0.63^{f}	0.15±0.004a	5.40 ± 0.002^{c}	130.1 ± 0.100^{b}
	50% of fertilizer	57.18 ± 0.017^{g}	0.48 ± 0.002^{b}	119.13 ± 0.45^{f}	0.12 ± 0.002^{c}	3.93 ± 0.002^{e}	179.2 ± 0.026^{a}
T6	100% of fertilizer	52.73 ± 0.030^{h}	0.51 ± 0.003^{d}	103.39 ± 0.48^{f}	0.13 ± 0.002^{c}	8.45 ± 0.004^{c}	92.00 ± 0.050^{f}
	75% of fertilizer	55.67 ± 0.051^{f}	0.44 ± 0.005^{d}	126.53 ± 1.43^{e}	0.09 ± 0.003^{e}	5.15 ± 0.005^{d}	97.60 ± 0.100^{c}
	50% of fertilizer	58.08 ± 0.020^{f}	0.45 ± 0.002^{c}	129.07 ± 0.54^{e}	0.11 ± 0.003^{d}	4.91 ± 0.003^{b}	105.07 ± 0.044^{c}
T7	100% of fertilizer	64.10 ± 0.046^{c}	0.45 ± 0.002^{g}	142.45 ± 0.73^{c}	0.15 ± 0.002^{b}	4.04 ± 0.002^{g}	40.37 ± 0.026^{h}
	75% of fertilizer	61.06 ± 0.030^{d}	0.35 ± 0.004^{f}	174.48 ± 2.20^{d}	0.12 ± 0.005^{c}	3.03 ± 0.003^{h}	57.35 ± 0.087^{g}
	50% of fertilizer	62.58 ± 0.030^{d}	0.39 ± 0.003^{d}	160.47 ± 1.02^{c}	0.10 ± 0.004^{e}	2.70 ± 0.001^{g}	41.47 ± 0.009^{f}
T8	100% of fertilizer	65.44 ± 0.017^{a}	0.38 ± 0.003^{i}	172.22 ± 1.17^{a}	0.11 ± 0.004^{e}	2.92 ± 0.003^{i}	102.6 ± 0.046^{d}
	75% of fertilizer	67.07 ± 0.030^{c}	0.36 ± 0.002^{e}	186.31 ± 0.97^{c}	0.13 ± 0.005^{b}	3.21 ± 0.001^{g}	48.78 ± 0.018^{h}
	50% of fertilizer	63.48 ± 0.036^{c}	0.28 ± 0.002^{h}	226.72 ± 1.28^{a}	0.13 ± 0.002^{b}	3.67 ± 0.004^{f}	32.60 ± 0.005^{i}
T9	100% of fertilizer	63.80 ± 0.046^{d}	0.42 ± 0.002^{h}	151.91 ± 0.53^{b}	0.13 ± 0.003^{c}	3.79 ± 0.001^{h}	28.99 ± 0.018^{i}
	75% of fertilizer	68.48 ± 0.026^{b}	0.35 ± 0.003^{f}	195.66 ± 1.43^{b}	0.10 ± 0.002^{d}	2.59 ± 0.002^{i}	37.64 ± 0.015^{i}
	50% of fertilizer	73.25 ± 0.030^{b}	0.32 ± 0.004^{f}	228.94 ± 3.23^{a}	0.08 ± 0.002^{f}	2.08 ± 0.003^{i}	40.91 ± 0.015^{g}

Table 6.2: Continued

Growth media	Fertilizer	Element							
		Ca (mg/l)	Fe (mg/l)	Mg (mg/l)	Zn (mg/l)	Al (mg/l)	Mn (mg/l)	Na (mg/l)	Other
T1	100% of fertilizer	199.30±0.230^{a}	25.92±0.035^{i}	12.55±0.010^{c}	0.096±0.002^{g}	61.11±0.017^{e}	0.12±0.002^{h}	25.13±0.044^{e}	≤0.01
	75% of fertilizer	80.83±0.026^{e}	26.17±0.017^{h}	12.29±0.010^{c}	0.72±0.001^{c}	71.32±0.010^{c}	3.86±0.003^{a}	14.61±0.025^{e}	≤0.01
	50% of fertilizer	33.69±0.017^{h}	35.04±0.015^{f}	9.83±0.007^{f}	3.21±0.028^{a}	83.71±0.030^{a}	0.54±0.002^{i}	7.63±0.002^{h}	≤0.01
T2	100% of fertilizer	39.28±0.020^{g}	147±0.173^{a}	17.19±0.010^{b}	2.58±0.065^{a}	319.8±0.154^{a}	2.20±0.003^{b}	45.35±0.050^{a}	≤0.01
	75% of fertilizer	76.54±0.010^{g}	116.90±0.13^{a}	26.07±0.030^{a}	3.25±0.001^{a}	306.30±0.12^{a}	2.93±0.005^{b}	39.05±0.030^{a}	≤0.01
	50% of fertilizer	98.06±0.017^{d}	42.71±0.017^{c}	32.67±0.10^{a}	2.62±0.010^{b}	71.84±0.010^{b}	0.65±0.002^{g}	22.53±0.56^{a}	≤0.01
T3	100% of fertilizer	33.07±0.017^{h}	62.67±0.017^{c}	5.86±0.002^{i}	0.52±0.001^{d}	70.39±0.010^{d}	1.82±0.003^{c}	15.49±0.020^{g}	≤0.01
	75% of fertilizer	46.27±0.020^{h}	37.87±0.020^{e}	9.88±0.005^{e}	0.41±0.001^{e}	60.4±0.020^{d}	1.16±0.003^{f}	13.12±0.009^{g}	≤0.01
	50% of fertilizer	82.51±0.017^{f}	30.94±0.020^{g}	14.16±0.046^{d}	0.28±0.001^{f}	53.85±0.020^{d}	0.60±0.003^{h}	10.29±0.012^{f}	≤0.01
T4	100% of fertilizer	48.91±0.030^{f}	32.54±0.017^{g}	11.73±0.020^{d}	0.11±0.002^{g}	7.18±0.003^{i}	0.60±0.003^{g}	28.65±0.010^{d}	≤0.01
	75% of fertilizer	41.78±0.030^{i}	39.89±0.030^{d}	5.06±0.003^{i}	0.14±0.003^{i}	7.35±0.002^{h}	0.83±0.001^{i}	14.03±0.040^{f}	≤0.01
	50% of fertilizer	24.28±0.020^{i}	50.44±0.020^{b}	8.69±0.003^{g}	0.50±0.006^{d}	32±0.050^{f}	2.16±0.004^{b}	8.33±0.004^{g}	≤0.01
T5	100% of fertilizer	75.15±0.010^{d}	103±0.100^{b}	19.77±0.026^{a}	1.38±0.022^{b}	99.98±0.036^{b}	3.53±0.006^{a}	32.57±0.020^{c}	≤0.01
	75% of fertilizer	93.01±0.017^{c}	55.17±0.026^{b}	18.92±0.020^{b}	0.77±0.001^{b}	95.27±0.017^{b}	2.72±0.005^{c}	23.66±0.080^{b}	≤0.01
	50% of fertilizer	122.80±0.087^{b}	53.82±0.026^{a}	31.45±0.026^{b}	0.72±0.004^{c}	67.28±0.020^{c}	2.11±0.003^{c}	17.73±0.012^{b}	≤0.01
T6	100% of fertilizer	18.15±0.020^{i}	48.35±0.030^{e}	8.39±0.002^{f}	0.40±0.002^{e}	79.36±0.017^{c}	2.19±0.006^{b}	35.27±0.020^{b}	≤0.01
	75% of fertilizer	102.10±0.11^{b}	42.28±0.010^{c}	12.2±0.020^{d}	0.48±0.003^{d}	60.2±0.020^{e}	1.01±0.006^{g}	20.18±0.022^{c}	≤0.01
	50% of fertilizer	128.90±0.030^{a}	35.17±0.044^{e}	14.49±0.026^{c}	0.27±0.001^{f}	36.51±0.011^{e}	0.83±0.001^{e}	15.68±0.023^{c}	≤0.01
T7	100% of fertilizer	78.14±0.020^{c}	57.59±0.030^{d}	6.58±0.002^{g}	0.43±0.004^{e}	14.38±0.010^{f}	1.49±0.003^{e}	13.92±0.030^{h}	≤0.01
	75% of fertilizer	106.70±0.13^{a}	24.12±0.020^{i}	8.10±0.002^{h}	0.34±0.002^{f}	10.64±0.010^{g}	1.25±0.003^{e}	9.25±0.010^{i}	≤0.01
	50% of fertilizer	82.63±0.030^{e}	17.38±0.030^{i}	10.18±0.017^{e}	0.32±0.003^{e}	8.79±0.003^{h}	0.84±0.002^{d}	12.58±0.030^{e}	≤0.01
T8	100% of fertilizer	103.80±0.050^{b}	31.11±0.040^{h}	11.39±0.010^{e}	0.22±0.002^{f}	11.03±0.010^{g}	1.04±0.001^{f}	13.62±0.040^{i}	≤0.01
	75% of fertilizer	76.78±0.030^{f}	31.94±0.017^{f}	8.32±0.005^{g}	0.26±0.001^{h}	12.12±0.020^{f}	1.48±0.003d	10.73±0.028^{h}	≤0.01
	50% of fertilizer	71±0.062^{g}	38.01±0.010^{d}	8.22±0.020^{h}	0.50±0.001^{d}	12.06±0.020^{g}	2.55±0.002a	6.92±0.003^{i}	≤0.01
T9	100% of fertilizer	60.22±0.010^{e}	38.66±0.026^{f}	6.43±0.002^{h}	0.66±0.004^{c}	10.13±0.017^{h}	1.70±0.002^{d}	21.31±0.010^{f}	≤0.01
	75% of fertilizer	92.13±0.060^{d}	27.68±0.030^{g}	9.56±0.005^{f}	0.30±0.001^{g}	7.16±0.026^{i}	0.89±0.002^{h}	17.42±0.020^{d}	≤0.01
	50% of fertilizer	106.10±0.044^{c}	28.76±0.046^{h}	8.19±0.002^{h}	0.20±0.005^{g}	8.72±0.001^{i}	0.73±0.001^{f}	13.45±0.025^{d}	≤0.01

Means with different letters are significantly different at $P \leq 0.05$ using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

6.5.2 Plant Growth Characteristics

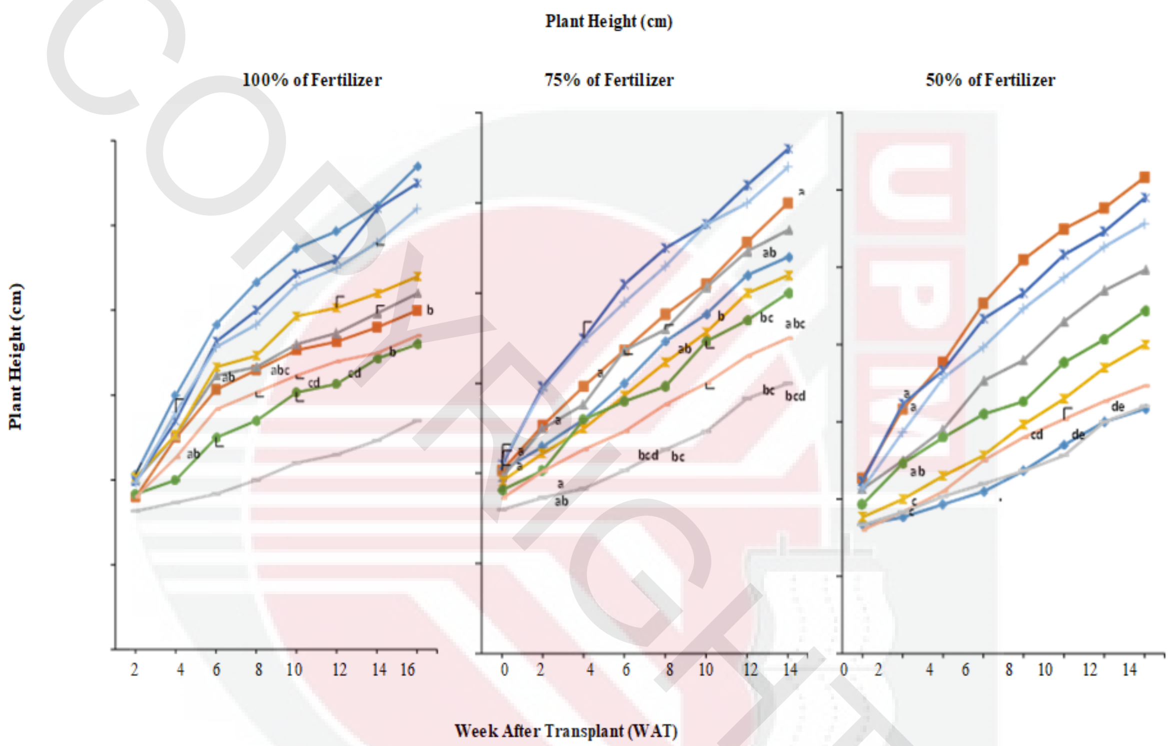
6.5.2.1 Plant Height

From Appendix J-h, analysis of variance shown the effect of different growth media in three different fertilizer rates was highly significant (P≤0.05) on plant height (cm). Appendix J-h also justified that the plant height in different growth media was no significant affected by three different fertilizer rates at 2WAT to 4WAT. However, plant height in different growth media was significantly (P≤0.05) affected by three different fertilizer rates started from 6WAT to 16WAT. Figure 6.4 illustrated that all growth media resulted in upward trend of plant height (cm) in across the week of transplants from 2WAT to 16WAT. The plant height in all growth media shown the increased pattern except plant height in T1, T4, and T8 when decreased the fertilizer rates. The different fertilizer rates consist of 100% of fertilizer rate, 75% of fertilizer rate, and 50% of fertilizer rate.

Meanwhile, Plate 6.1, Plate 6.2, and Plate 6.3 shown the plant growth during 14 weeks of planting in 100%, 75%, and 50% of fertilizer rates (start transplant the seedling at age 21days). According to Figure 6.4, the plant height in T2 increased from 40.0cm to 62.0cm when reduced the fertilizer rates from 100% to 50% of fertilizer rates. T2 also demonstrated as the highest plant height (62.0cm), followed by T5 (59.0cm) and T7(56.0cm) in 50% fertilizer rate compared to other growth media. From the result, the optimum amount of growth media T2 (100% of coconut ash), T5 (2CCD:1CA), and T7 (3CCD:1PKSB) improved the plant height by reduced the fertilizer rates in

50% from standard fertilizer rates on chilli plant. Putra et al. (2017) reported that ornamental chilli "Lembayung" grown in growth media (Charcoal husk:soil:manure) was the tallest from 2 to 12 WAP. Wasis et al.(2019) studied about the application of coconut shell charcoal and NPK fertilizer toward *Acacia mangium* growth on the soil of ex-limestone mining. Wasis et al.(2019) found that Coconut shell charcoal and NPK fertilizer resulted in highest of plant height (0.91cm) of *A.mangium* seedlings. According to Baon (2009), plant derived ash (PDA) can supply essential nutrient elements to plants grown on nutrient deficient soils due to increase(high) in pH and CEC.

Application of fly ash has been reported toimprove plant growth grown in deficient nutrient soils (Levula et al., 2000, Jacobson,2003). Baon (2009) found that cocoa plants applied with 900 mg K2O applied as PDAsh per 2.5 kg soil had the highest plant height at 8 weeks after treatment due to the optimum balance condition among nutrients in soil which eventually resulted in better growth. Mittra et al. (2003) found that utilizing ash-organic solid mixture can reduce the use chemical fertilizers and improve the plant growth. Meanwhile, the plant height in T1 and T8 declined to 32.0cm when reduced the fertilizer rates and indicated as the lowest of plant height in 50% of fertilizer rate compared to other growth media due to deficiency of nutrient for plant growth causes stunted of growth (Uchida,2000). Moreover, the decrease of pH and CEC occur when reduce the fertilizer rate will disturb the nutrient availability, mobility, and imbalance the uptake of water and nutrients for crops (Ağar,2011; Neina,2019).



Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB.

Where, T1 T2 T3 T4 T5 T6 T7 T8 T9

Figure 6.4 : The effect of different growth media on plant height along the week after transplant (WAT) in three different fertilizer rates

F1 (100% Fertilizer rate)

Plate 6.1 : Plant growth during 14 weeks of planting in 100% of fertilizer rate (start transplant the seedling at age 21days). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD:1PKSB, T9=1CCD :1PKSB

F2 (75% Fertilizer rate)

Plate 6.2 : Plant growth during 14 weeks of planting in 75% of fertilizer rate (start transplant the seedling at age 21days). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

F3 (50% Fertilizer rate)

Plate 6.3 : Plant growth during 14 weeks of planting in 50% of fertilizer rate (start transplant the seedling at age 21days). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

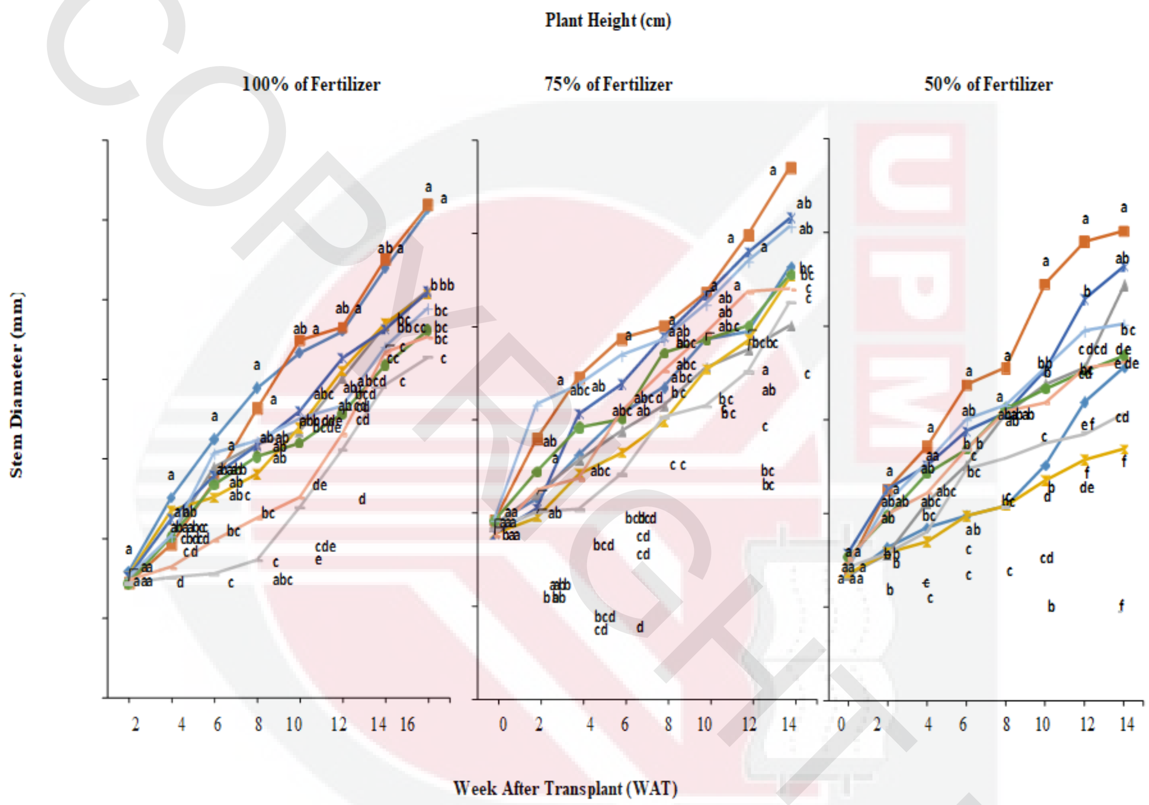
6.5.2.2 Stem Diameter

Appendix J-i illustrated that the stem diameter in different growth media was no significantly affected by three different fertilizer rates at 2WAT to 4WAT. However, the stem diameter in different growth media was significantly ($P \leq 0.05$) affected by three different fertilizer rates (Appendix J-i) from 6WAT to 16WAT. The analysis of variance shown in Appendix J-i also proven that the effect of different growth media in three different fertilizer rates was highly significant ($P \leq 0.05$) on stem diameter of chilli (mm) at 4WAT to 16WAT. Meanwhile, different growth media in three different fertilizer rates was no significantly affected on stem diameter of chilli (mm) at 2WAT.

Figure 6.5 illustrated that all growth media resulted in increased trend of stem diameter (mm) in across the week of transplants from 2WAT to 16WAT. Emir et al., (2018) found that plant height and stem diameter of chili pepper increased in each week of observation. The similar result also reported by Anggraheni et al. (2019) the stem diameter of chili pepper significantly increased on each treatment observed at 30 DAP, 60 DAP, and 90 DAP. Moreover, Pegoraro et al.(2014) also state the stem diameter shown the upward trend during the growth cycle of ‘Vitória’ pineapple plants in days after planting (DAP). Meanwhile, the diameter of stem in all growth media shown the declined pattern when decreased the fertilizer rates. The similar result found by Du et al.(2021) where the stem diameter of tomato plants at 20 DAT (4.55mm), 40 DAT (11.63mm) and 60 DAT (13.84mm) in 840 kg/ha of fertilizer rate were lower than stem diameter of tomato plants at 20 DAT (5.07mm), 40 DAT (13.16mm) and 60 DAT (14.27mm) in 990 kg/ha of fertilizer rate. The different fertilizer rates consist of100% of fertilizer rate, 75% of fertilizer rate, and 50% of fertilizer rate.

From Figure 6.5, T2 proven as the highest stem diameter (10.02mm), followed by T5 (9.26mm) and T3(8.86mm) in 50% fertilizer rate compared to other growth media. Plant height and stem diameter were influenced by K nutrient uptake (Hartatik et al., 1999). K nutrient play a role in accelerating growth of meristem tissues (Marschner, 1995). The similar result reported by Baon (2009) where the lowest stem diameter (7.74mm) and plant height (33.35cm) of cocoa when applied 1500 mg K_2O applied as PDAsh per 2.5 kg soil, meanwhile the highest stem diameter (9.34mm) and plant height (43.81cm) found when applied 900 mg K_2O applied as PDAsh per 2.5 kg soil.

The result found by Baon (2009) proven that the highest plant height and stem diameter resultant by decrease in nutrient concentration to reach the optimum balance condition among nutrients in growth media (Awang et al.,2009). In contrast, the lowest of stem diameter was in T4 with 5.36mm in 50% of fertilizer rate compared to other growth media as shown in Figure 6.5 due to insufficient of nutrient supply (especially K nutrient) that accelerating growth of meristem tissues (Marschner, 1995; Baon,2009; Bukhsh et al.,2012). The similar result reported by Du et al.(2021) where the stem diameter of tomato plants (13.84mm) become low when apply 840 kg/ha of fertilizer rate compared with stem diameter of tomato (14.27mm) in 990 kg/ha of fertilizer rate.



Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB.

Where, T1 T2 T3 T4 T5 T6 T7 T8 T9

Figure 6.5 : The effect of different growth media on stem diameter across the week after transplant (WAT) in three different fertilizer rates

6.5.2.3 Days of Flowering

Table 6.3 shown the day of flowering at different flowering stages in different growth media in three different of fertilizer rates. The flowering stages on chilli plant that be analyze in this experiment consist of initial flowering, 50% of flowering, and fruit set. The analysis of variance demonstrated the effect of different growth media were significant difference ($P \leq 0.05$) on day of flowering at initial flowering, 50% flowering and fruit set in three different of fertilizer rates by refer to Appendix J-j. Moreover, day of flowering at initial flowering, 50% flowering and fruit set in different growth media were significantly ($P \leq 0.05$) affected by three different fertilizer rates (Appendix J-j). Table 6.3 illustrated that day of initial flowering, 50% flowering, day of initial fruit set of *Capsicum annuum L. Var. Kulai* in all growth media become decreased when reduced the fertilizer rates except for T1, T4 and T8.

According to Table 6.3, initial flowering in T2 started at 44.67, 43.00, 41.67 days from day of transplant (DAT) in 100%, 75%, and 50% of fertilizer rates. The initial flowering, 50% flowering and fruit set in T2 started in early day of flowering at 41.67,46.00, and 52.00 days in 50% of fertilizer rate compared to other growth media. Meanwhile, T5 also demonstrated as the second shortest days to initial flowering, 50% flowering and fruit set at 42.00, 46.33, and 52.00 days in 50% of fertilizer rate compared to other growth media. Contrast with T8 that took the longest days at 46.00, 51.67, and 57.00 days to reached the initial flowering, 50% of flowering, and fruit set in 50% of fertilizer rate compared to other growth media, and resultant in delay of 4 to 5 days by compared with days of flowering stages in T2. Kpinkoun et al.,2019 found that the flowering duration of chili plant become short when reduce the salinity in fertilizer from 40.33 days to 31.66 days respectively. Thus, the reduce of salinity resultant in early of the flowering. Day (2000) also reported that optimum supply of boron stimulated the uptake of phosphorus by plant roots and promoted more flower clusters formation, as phosphorus directly promotes flowering. Kolář and Seňková (2008) reported that the time from sowing to bud appearance of Arabidopsis was significantly shortened with decreasing concentration of nutrients.

The optimum of N, P, K fertilization promoted the early flowering of plant. These nutrients affect the growth and development of plant through different physiological and metabolic processes, and thus affect the flowering. However, the response of flowering to the P and K fertilizer was not as sensitive as that of N fertilization (Ye et al.,2019). Several studies have shown that N is one of the factors that controlling flower, and N limitation often induces early flowering (Liu *et al.*, 2013; Vidal et al., 2014; Lin and Tsay, 2017). The application of optimum N fertilizer significantly advanced and early the flowering compared to very high of N fertilizer rate that delayed the flowering (Liu et al., 2013; Vidal et al.,2014; Lin and Tsay, 2017). The application of N fertilizer generally played an apparent role in the promotion of flower development and booting (Wang et al., 2008). Nitrogen is the main component of protein, and all types of enzymes are mainly composed of proteins such as nucleic acid, nucleotides, coenzymes, phospholipids, and cytokinin. Plants could shorten their life cycle to achieve the maximum biological yield under deficiency N conditions (Kolář and Seňková, 2008). Therefore, advancing flowering is considered an escape strategy (Takeno, 2016; Bheemanahalli et al., 2017). The lower N or optimal N is the optimal concentration for flowering in growth media, meanwhile superior N concentrations could enhance the plant growth and tiller but delayed flowering.

However, N limiting and N starvation concentrations are lower than optimal N and delay flowering because N starvation concentrations cause severe growth retardation (Lin and Tsay, 2017). The initial fruit set influences by air temperatures, weather conditions, foraging activity of pollinators, pollination and fertilization rate (Seeley 2009; Tuell and Isaacs, 2010; Courcelles et al., 2013). According to Arrington (2017), the delay of initial fruit set potentially due to the effect of low air temperatures during bloom, which have reduced the foraging activity of pollinators, leading to reduced pollination, fertilization and fruit set

Table 6.3 : The effect of different growth media in three different fertilizer rates on the day of flowering at different flowering stages

Growth media	Fertilizer rate	Day of Flowering		
		Initial of flowering (DAT)	50% of flowering (DAT)	Fruit set (DAT)
T1	100% of fertilizer	42.00±0.00^{c}	46.33±0.58^{d}	52.33±1.53^{b}
	75% of fertilizer	43.33±1.15^{abc}	49.00±0.00^{b}	55.00±0.00^{ab}
	50% of fertilizer	46.00±1.00^{cd}	51.00±0.00^{bc}	57.00±2.00^{a}
T2	100% of fertilizer	44.67±0.58^{b}	50.33±0.58^{b}	57.00±1.73^{ab}
	75% of fertilizer	43.00±0.00^{abc}	48.33±0.58^{bc}	54.33±0.58^{ab}
	50% of fertilizer	41.67±0.58^{bc}	46.00±1.00^{c}	52.00±1.00^{d}
T3	100% of fertilizer	44.00±0.00^{b}	49.33±0.58^{bc}	55.67±1.53^{ab}
	75% of fertilizer	42.67±0.58^{bc}	48.00±1.00^{bc}	54.00±1.00^{ab}
	50% of fertilizer	42.67±0.58^{a}	47.00±1.00^{a}	53.00±1.00^{cd}
T4	100% of fertilizer	44.00±0.00^{b}	49.00±0.00^{bc}	55.00±1.73^{ab}
	75% of fertilizer	45.00±0.00^{ab}	50.67±0.58^{a}	56.67±0.58^{a}
	50% of fertilizer	45.00±1.00^{d}	50.67±0.58^{d}	57.00±1.00^{ab}
T5	100% of fertilizer	43.33±0.58^{bc}	48.67±0.58^{c}	54.67±1.53^{ab}
	75% of fertilizer	41.67±1.15^{c}	47.00±0.00^{c}	53.00±2.00^{b}
	50% of fertilizer	42.00±0.00^{bcd}	46.33±0.58^{bc}	52.00±1.73^{cd}
T6	100% of fertilizer	46.67±0.58^{a}	50.33±0.58^{b}	56.33±1.53^{ab}
	75% of fertilizer	44.00±1.00^{abc}	49.00±0.00^{b}	54.67±0.58^{ab}
	50% of fertilizer	43.67±0.58^{cd}	48.00±0.00^{bc}	54.00±1.00^{bc}
T7	100% of fertilizer	43.33±0.58^{bc}	48.33±0.58^{c}	55.00±2.00^{ab}
	75% of fertilizer	42.00±0.00^{c}	47.33±0.58^{c}	53.00±0.00^{b}
	50% of fertilizer	42.00±0.00^{cd}	46.33±0.58^{d}	52.33±1.53^{cd}
T8	100% of fertilizer	44.33±1.15^{b}	49.33±0.58^{bc}	55.00±2.00^{ab}
	75% of fertilizer	45.33±0.58^{a}	50.67±0.58^{a}	56.67±0.58^{a}
	50% of fertilizer	46.00±1.00^{cd}	51.67±0.58^{b}	57.00±1.73^{a}
T9	100% of fertilizer	47.33±0.58^{a}	52.00±1.00^{a}	58.00±1.73^{a}
	75% of fertilizer	45.00±1.00^{ab}	50.67±0.58^{a}	56.67±1.15^{a}
	50% of fertilizer	45.00±0.00^{ab}	50.67±0.58^{bc}	56.67±0.58^{ab}

Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB.

6.5.2.4 Number of Fruit

The analysis of variance (ANOVA) justified that the effect of different growth media in three different fertilizer rates was highly significant (P≤0.05) on number of harvested fruit (Appendix J-k). Moreover, number of harvested fruit (yield) in all growth media was significantly (P≤0.05) affected by 100% of fertilizer rate, 75% of fertilizer rate, and 50% of fertilizer rate. According to Figure 6.6, all growth media resulted in increased trend of number of harvested fruit (yield) except in T1 and T8 in reduced the fertilizer rates. The number of harvested fruits in T2 shown the increased trend from 20 to 61 when reduced the fertilizer rates (Figure 6.6). Moreover, T2 also demonstrated as the highest number of yields of 61, followed by T5 (58) and T7 (57) in 50% fertilizer rate compared to other treatments. According to Harjoko et al.(2018), rice-husk charcoal(ash) produced the highest number of Hot Beauty chili yield (186) compared to other growth media. In contrast, the number of yields in T8 was declined from 18 to 15 when reduced the fertilizer rates. According to Figure 6.6, T8 contained the lowest number of yields of 15, followed by T1 and T9 with 18 of number of harvested fruits in 50% of fertilizer rate compared to other growth media. The number of fruit (yield) influences by total leave area and chlorophyll content.

The increase of total leave area and chlorophyll content will be increased photosynthetic activity and rate at which ultimately resulted in higher number of fruits per plant and seed yield per ha (Singh et al.,1989; Khandaker et al.,2017). Moreover, Zakaria et al.(2020) justify that the reduction in total fruit fresh weight of root-restricted chilli plants was more related to the reduction in the number of fruits and low plant dry matter production due to lower total leaf area and chlorophyll content. The level nutrient content in growth media (especially N, P, K) influences the number of yield production (Thapa et al.,2016).

According to Indirabai and Sujapratha (2009), the high level of nutrients in growth media able to promote growth, advance flowering and fruiting. Moreover, the reduce of number and weight of yield caused by pest attack and diseases infection on chilli crop during vegetative and reproductive stages (Hussain and Abid, 2011). The fruit borer (Helicoverpa armigera) and fruit fly (Bactrocera dorsalis) mostly attack the fruit during reproductive stage by sucking and damage the fruit that reduce the fruit (yield) quality and production (Sharma et al.,2017). According to Hussain and Abid (2011), the yield of chilli is reducing gradually every year due to different pests and pathogens which cause heavy losses.

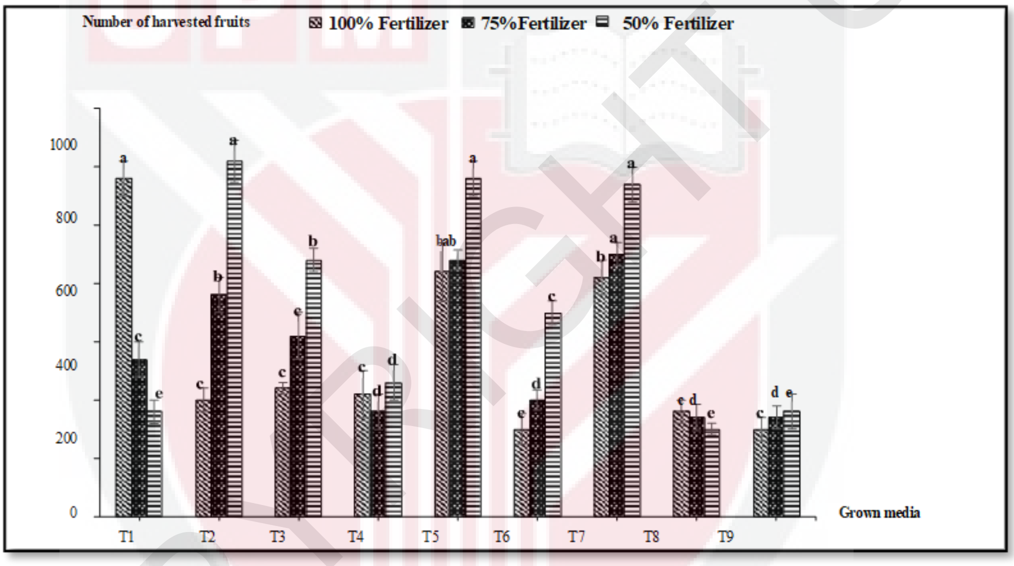


Figure 6.6 : The effect of different growth media on number of harvested fruit (yield) in three different fertilizer rates. Means with different letters are significantly different at P P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD:1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

6.5.2.5 Weight of Fruit (Yield)

From Appendix J-k, the analysis of variance proven that the effect of different growth media in three different fertilizer rates was highly significant (P≤0.05) on weight of harvested fruit. Moreover, weight of harvested fruit (yield) in all growth media was significantly (P≤0.05) affected by 100% of fertilizer rate, 75% of fertilizer rate, and 50% of fertilizer rate (Appendix J-k). Figure 6.7 illustrated that all growth media shown in increased trend of weight of harvested fruit (yield) except in T1 and T8 in reduced the fertilizer rates. The weight of harvested fruit in T2 increased from 318g to 1115g when reduced the fertilizer rates (Figure 6.7). Meanwhile, T2 indicated as the highest weight of yield of 1115g, followed by T5 (1009g) and T7 (1006g) in 50% fertilizer rate compared to other growth media. The similar result reported by Harjoko et al.(2018) when rice-husk charcoal(ash) produced the highest weight of Hot Beauty chili yield (673g) compared to other growth media. Mbah et al.(2013) proven that ash application to soil increased maize growth and yield. Bonneau et al. (2010) also reported that production of nuts from palms performed well when treated with coconut ash compared to a standard fertilizer. Oditte et al.(2005) and Ojeniyi et al. (2007) found that crop yield increased when ash was used as soil amendment.

Figure 6.7 shown that the weight of yield in T8 reduced from 334g to 283g when reduced the fertilizer rates, thus T8 contained the lowest highest weight of yield (283g) in 50% of fertilizer rate compared to other growth media due to insufficient of nutrient supply. The optimum of nutrient supply especially N, P and K directly influence growth, maturity, and yield and fruit quality. Chilli has also been shown to respond very well to application of fertilizer (Akande et al.,2008) and produced well when it is adequately supplied with the essential nutrients (Peck and MacDonald,1975). Aliyu et al. (1991) reported that day to 50% flowering, maturity days, number of fruits per plant, fruit diameter and length of chilli pepper was significantly affected by fertilizer application rate. Optimum dose of fertilizers increases the proper growth, development and maximize the yield of sweet pepper. Tumbare et al., (2004) reported that nitrogen and potassium fertilizer increased yield, the fruit weight and fruit number of chili peppers. Qawasmi et al., (1999) also reported that when optimum or ideal rates of nitrogen applied in pepper plants can increases the uptake of nitrogen by the plants, thus stimulating the uptake of potassium and phosphorus through the synergistic effect of nitrogen on them. The application of optimum dose of fertilizer is important to increase the pepper growth, development and maximize the yield of pepper.

The pH and CEC in growth media influence the nutrient availability to crops, thus effect the plant vegetative and yield productions. Similarly, research result by Odedina et al. (2003), Adetunji (1997) and Owolabi et al.(2003) showed reduced acidity, increased nutrient availability and CEC in soil of southwest Nigeria amended with ash application relative to the control. Moreover, the production of chilli can be affected by disease attack such as mosaic virus and Anthracnose. Study by Sukada et al. (2014), showed that the yield of chilli plants infected by the mosaic virus was only 2.52 tonnes/hectare, while healthy plant gives a production of 16 tonnes/hectare. That describes that the reduction of chilli yield due to viral mosaic infection reached 84.25%. Changes in fruit shape or malformations associated with symptoms that occur on the leaves, resulted in disruption of photosynthesis and inhibits the development of chilli, fruit does not grow normally causing the decline in the production of chilli (Damiri et al.,2018). Anthracnose disease has been reported to be a major constraint in chilli production in tropical subtropical countries causing huge losses that causing major damage at the ripe fruit stage of the plant (Ranathunge et al., 2012; Saxena et al., 2014). It causes fruit rot at both green and red stages primarily attacking ripe fruits that can reduce the chilli production at harvest stage (Agrios, 2005).

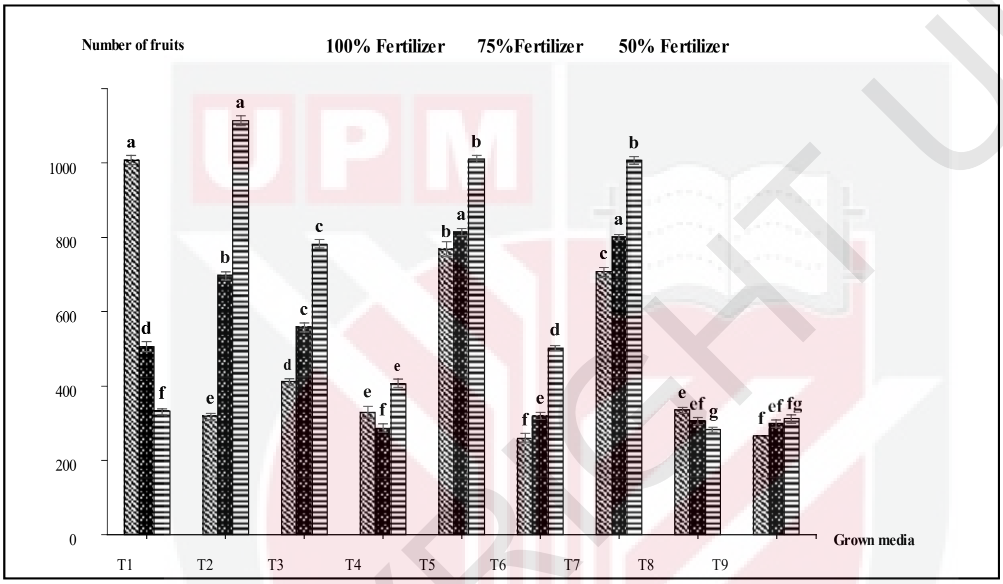


Figure 6.7 : The effect of different growth media on weight of harvested fruit (yield) in three different fertilizer rates. Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

6.5.2.6 Total Leaf Area (TLA)

According to Appendix J-I, the analysis of variance proven that the effect of different growth media in three different fertilizer rates was highly significant (P≤0.05) difference on total leaf area. Moreover, the total leaf area in all growth media was significantly (P≤0.05) affected by three different fertilizer rates. Figure 6.8 represented the total leaf area in all growth media shown in upward trend except for total leaf area in T1, T3, T4, and T8 when reduced the fertilizer rates. Figure 6.8 illustrated that the total leaf area in T2 rose from 1602.44cm^2 to 3807.88cm^2 when reduced the fertilizer rates. Moreover, T2 contained the highest total leaf area of 3807.88cm^2, followed by T5 (3225.12cm^2) in 50% fertilizer rate compared to other growth media. Baon (2009) reported that application of Plant Derived Ash (PDA) from coconut significantly improve leaf area of cocoa plants. Baon (2009) also found that cocoa plants applied with 900 mg K_2O and 700 mg of PDAsh per 2.5 kg soil had the highest leaf area of cocoa plants compared with leaf area applied with 1200 mg K_2O and 1500 mg K_2O. The improved growth may be due to the optimum balance condition and salinity among nutrients in soil which eventually resulted in better growth (Baon,2009).

According to Hartatik et al. (1999) leaf number and leaf area were improved by the better uptake by Mn nutrient, whereas the status of this nutrient in soil was moderate. Marschner (1995) indicated that Mn has a big role in the formation of chlorophyll and as catalyst for several metabolism processes and protein formation. Baon (2009) also stated that Plant derived ash of coconut can also supply essential nutrient elements to plants grown on nutrient deficient soils, reduction in the use chemical fertilizers and its capacity as liming materials which is due to the very alkaline characteristic in pH. Ichwani and Mapegau (2020) also reported that coconut husk biochar gave a significant effect on leaf area and total dry weight of maize plant at age 8WAP and the greatest increase of leaf area and total dry weight of maize plant was found in 15 tons ha^{-1} of coconut husk biochar. The leaf area of maize planted with coconut husk biochar was higher than the leaf area without coconut husk biochar (Ichwani and Mapegau, 2020). The similar result also found by Dao et al.(2013), where the leaf area index of maize plant was increased two-fold when application of coconut shells biochar.

The leaves are plant organs that carry out photosynthesis, thus the size of the leaf area will determine the amount of substrate produced during photosynthesis. Application of optimum doses of biochar and fertilizer rates can increase the leaf area of plants. An increase in plant leaf area closed related to an increase in plant uptake of P and K nutrient content. Biochar application increases P and K compared to without biochar (Ichwani and Mapegau, 2020). Phosphorus (P) in plants is an energy transfer component (ADP, ATP and nuclei protein), genetic information systems (DNA and RNA), cell membranes (phospholipids) and phosphoproteins (Gardner et al., 1985). P also plays a role in the photosynthetic intermediaries' phosphorylation and respiration (Loveless, 1991). The increase in P in maize plant increases the ability of plants to carry out photosynthesis in line with the increase in leaf area. Potassium (K) plays an important role in the process of photosynthesis by increasing plant growth and leaf area index, increasing CO_2 assimilation and photosynthate translocation (Gardner et al., 1985). Increased growth of maize plants caused by increased K content in plant tissue. The effects of biochar addition on plant dry biomass and nutrition were dependent upon the biochar type and application rate (Ichwani and Mapegau, 2020).

According to Hanudin et al. (2021), the widest leaf area of mustard plant was obtained in the combination growth media of 900g/pot cow manure with 100g/pot of coconut ash treatment. According to Awotoye (2014), coconut ash contained the high nitrogen content. The most important nutrient used for leaf development is nitrogen. Nitrogen functions to increase vegetative growth so that the leaves become wider and quality, characterized by greener leaves (Natasya et al.,2014). Moreover, coconut ash can supply potassium nutrients which are also needed by mustard plants. Potassium functions to activate various enzymes, metabolic processes, maintain turgor, regulate the movement of stomata, form ATP, increase nitrogen absorption and protein synthesis and starch synthesis (Loide,2004). Combination of optimal dose of 900g/pot Cow manure with 100g/pot of coconut ash able to increase the K and Ca uptake of mustard greens. Moreover, total leave area of *Capsicum annuum L. Var. Kulai* increased when reduced the fertilizer rates due decreased of EC level and reach the optimum salinity in growth media that improved the plant growth. Ali et al.(2004) reported that the high salinity reduced the leaf area of rice by shrinkage of the cell contents, reduced development and differentiation of tissues, unbalanced nutrition, damage of membrane and disturbed avoidance mechanism. The reduction in leaf area under saline conditions were also due to reduced growth as a result of decreased water uptake, toxicity of sodium and chloride in the shoot cell as well as reduced photosynthesis.

Samarakoon et al.(2006) reported that increased electrical conductivity (EC) of the nutrient solution reduced the leave area of leaf lettuce. Lam et al. (2020) also found the leaf area of *Agastache rugosa* in 4.0 $dS{\cdot}m^{-1}$ treatment was the highest and leaf area 8 dS·m^{-1} treatment was the lowest due to salinity stress ion imbalance, toxicity, lower water uptake, and turgor pressure in the plant, and the variation in osmotic potential around the roots. In addition, the ion ratio and concentration of the Nutrient Solution affect the uptake and translocation between each part of the plant. Therefore, the growth of *Agastache rugosa* was improved under the optimal EC treatments (2.0 to 4.0 dS·m^{-1}). Lam et al. (2020) also indicated that the high EC reduced the osmotic potential of the Nutrient Solution, which reduce the water uptake and turgor pressure in the plant. Furthermore, a high EC may limit cell expansion due to the diminished water uptakeand turgor pressure. A high EC may lead to the retention of toxic ions in the root zone, so ion imbalance may affect plant growth. Therefore, plant growth was decreased by a high EC (Albornoz and Heinrich Lieth, 2015); Pecanha et al.,2017). Moreover, the increase in Cl^- and Na^+ may limit the Ca^{2+} and K^+ uptake of roots because the hydrated radii of potassium and calcium are higher than that of sodium. A low K^+/Na^+ selectivity ratio result from a high-affinity potassium transport system. Therefore, ion imbalance occurs under salinity stress (Amalfitano et al.,2017; Degl'Innocenti et al.,2009). According to Degl'Innocenti et al. (2009), plant growth was significantly decreased in barley species because the osmotic potential was reduced and ion imbalance arose around the roots.

Meanwhile, T8 shown the decreased trend of total leaf area from 1802.1cm^2 to 750.3cm^2 in decreased of fertilizer rates, thus T8 indicated as the lowest total leaf area of 750.3cm^2 in 50% of fertilizer rate compared to other growth media as refer to Figure 6.8. Heinen et al.(2001) indicated that crop growth reduction occurs at low EC. Low EC indicate that not enough nutrients available to the roots resulting in a reduction of nutrient uptake, and reduced crop growth and development. At low EC of the fertigation water also resultant in less nutrient uptake occurs resulting in low nutrient concentrations in the plant. According to Heinen et al.(2001), the leaf area of tomato reached maximum value at optimum EC, while lowest leaf area at lowelectrical conductivity in nutrient solution. Moreover, disease attack such as mosaic virus on leaves can decrease the leaf area, chlorophyll concentrations and further interfere the metabolic processes (Damiri et al.,2018). Mosaic virus infection can cause discoloration of leaves (mosaic) such as dark green striped leaves or light greenstriped leaves, leaf curl, narrow, shrunken, small(dwarf) and necrosis.

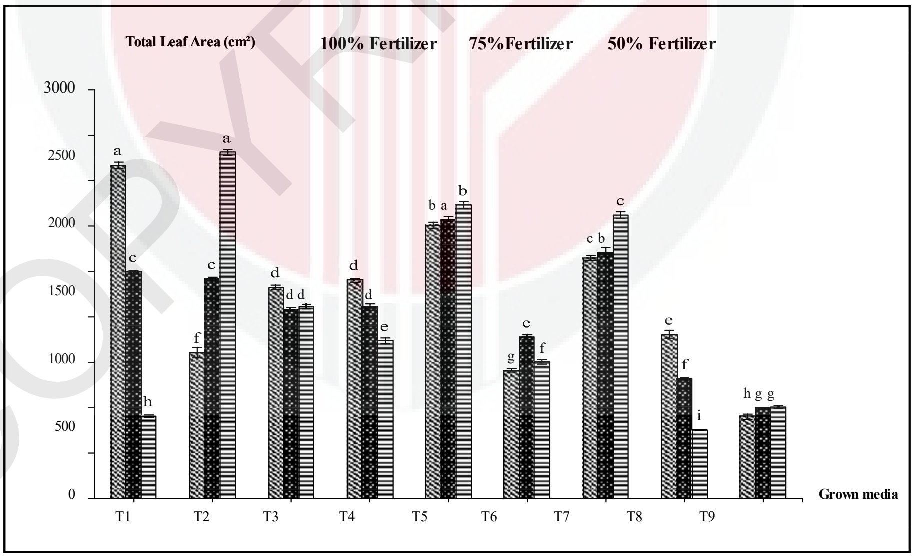


Figure 6.8 : The effect of different growth media on total leaf area in three different fertilizer rates. Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

6.5.2.7 Chlorophyll Content

The analysis of variance justified the effect of different growth media in three different fertilizer rates was highly significant ($P \leq 0.05$) difference on chlorophyll content (Appendix J-p). Appendix J-p also illustrated the chlorophyll content in all growth media was significantly ($P \leq 0.05$) affected by three different fertilizer rates. According to Figure 46, the growth media T2, T3, T5, T7, and T9 resulted in upward trend of chlorophyll content when reduced the fertilizer rates from 100% to 75% of fertilizer rates. Meanwhile, the chlorophyll content in all growth media shown the increased pattern except chlorophyll content in T1, T4, T6 and T8 from 100% to 50% of fertilizer rates. Figure 6.9 shown that T2 contained the highest chlorophyll content with 66.2, followed by T5 (62.5) in 50% fertilizer rate compared to other growth media.

There isnot much research on the effect of coconut ash on the chlorophyll content of crop. However, Shakeel et al.(2019) found that 30% of fly ash resulted in maximum chlorophyll content 1.45 mg^{-1} g of B. juncea compared with control and 50% of fly ash amendment. Ran et al.(2020) also justify that shell biochar treatment increase leaf chlorophyll content index and significant difference ($P<0.05$) was found between biochar treatments and B0 (zero-biochar). Similar result was obtained by Akhtar et al. (2015), biochar application significantly increased the chlorophyll content index at heading stage due to the increase of N content in leaves. Biochar addition in soil increased total nitrogen (up to 7%) and organic carbon (up to 69%), while reducing nutrient leaching, thus resulting in decreased need for fertilizer (Laird et al., 2010a).

The chlorophyll is an essential component for photosynthesis occurs in chloroplasts a green pigment in all photosynthetic plant tissues, thus more chlorophyll content in plants is attributed to more uptake of nitrogen by the plants (Malik et al.,2011). According to Khandaker et al.(2017), nitrogen involve in the formation of chlorophyll which lead to an effective photosynthesis rate of chilli plant. In contrast, the chlorophyll content in T8 contained the lowest chlorophyll content of 38.5 in 50% of fertilizer rate compared to other growth media as refer to Figure 6.9. The decreased leaf chlorophyll content was caused by leaf N concentration and iron (Fe) availability (Huang et al.,2020). SPAD or chlorophyll content shows the N level of leaf tissue (Wood et al.,1993).

Thus, the low SPAD readings indicated low of leaf N concentration (Li et al.,1998). The adult leaves are discoloured to light green and become a little smaller than normal under N deficiency, thus it will affect the photosynthesis (Taghavi et al.,2004). Roosta and Hamidpour (2013) state that the ratio of variable florescence of the chlorophyll to the maximal florescence (Fv/Fm) increases as increases of photosynthesis. The variable florescence (Fv) which equals Fm-F0 will decreases when photosynthesis tract is stressed. N deficiency resultant in decreased amount of variable florescence (Fv). Fv/Fm decreases because of the increase in F0 under stress and injury. The decrease in or low level of chlorophyll will increase F0 because the remaining chlorophyll re-absorbs less light (Hak et al.,1993; Maxwell and Johnson,2000). The increased substrate pH could reduce iron (Fe) availability, thus cause the decrease of leaf greenness. Dickson et al.(2016) found that shoot Fe concentration was lower at substrate with higher pH, and leaf SPAD readings were significantly correlated with Fe availability since Fe is essential for the chlorophyll synthesis (Radhamani et al.,2016). Wallihan (1955) reported that the leafchlorosis could be more severe with less iron concentration. Moreover, the decreased leaf SPAD readings of the tomato plants due to the deficiency of nutrient of the leaves caused by the strong nutrient sink fruits and flowers (Huang et al.,2020).

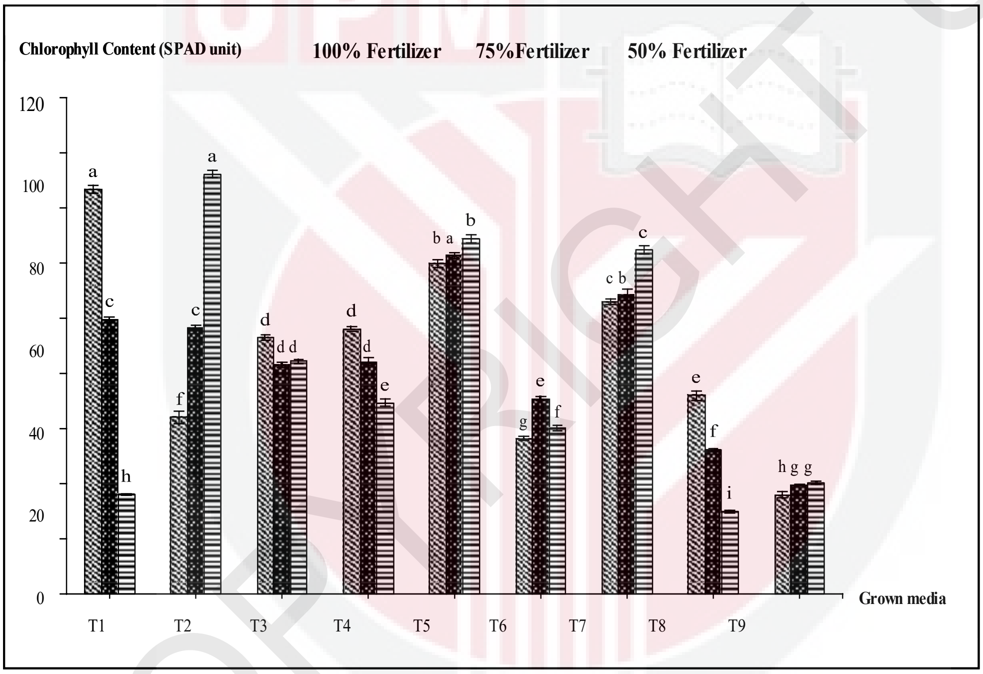


Figure 6.9 : The effect of different growth media on chlorophyll content in three different fertilizer rates. Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB

6.5.3 Root Size and Distribution

6.5.3.1 Root Length, Root Diameter, Root Surface Area and Root Volume

From Appendix J-m, the root length, root diameter, root surface area and root volume in three different fertilizer rates were significantly ($P \leq 0.05$) affected by different growth media. Meanwhile, the analysis of variance (ANOVA) proven that three different fertilizer rates were highly significant ($P \leq 0.05$) difference on root length, root diameter, root surface area and root volume in different growth media as refer to Appendix J-m. Table 6.4 represented the root length, root diameter, root surface area and root volume on different growth media in three different fertilizer rates. The root length in all growth media shown in upward trend except for T1, T2, T3 and T8 in reduced the fertilizer rates. Table 6.4 illustrated T4 contained the longest root length (621.0cm) in 50% fertilizer rate compared to other growth media. The similar result found by Fageria et al. (2014) when root length of Sunnhemp, Pigeonpea, and Lablab cover crops were increased about 9% to 23% when the reduction of 100 mg P kg^{-1} soil from 200 mg P kg^{-1} soil. Chen et al. (2020) also reported that total root length ofCotton increased in 240 kg ha^{-1} N compared to 480 kg ha^{-1} N. Meanwhile, T8 indicated as the shortest length of root with 226.4cm, followed by T1(228.04cm) in 50% fertilizer rate compared to other growth media. Fageria et al.(2014) reported thatroot length of tropical legume cover crops were reduced for 28% in control 0 mg P kg^{-1} treatment compared with 100 mg P kg^{-1} treatment.

Moreover, root length of Gray mucuna bean cover crop was reduced for 31% when the reduction of 100 mg P kg^{-1} soil from 200 mg P kg^{-1} (Fageria et al.,2014). The improvement in root length with the addition of P in crop plants in Brazilian Oxisols is reported also by Fageria and Moreira (2011), and Fageria (2016). Chen et al. (2020) also reported that total rootlength of Cotton reduced in 120 kg ha^{-1} N compared to 240 kg ha^{-1} N. From Table 6.4, all growth media shown the decreased pattern in root diameter except for T2, T7,and T9 when decreased the fertilizer rates. The largest of root diameter were in T2 andT7 with 1.73mm of diameter, meanwhile T1 contained the smallest root diameter (0.97mm) in 50% fertilizer rate compared to other growth media. Sun et al.(2010) and Chaukiyal et al.(2013) reported that the optimum N fertilization significantly increasesthe diameter of *Larix gmelinii* root tips and the growth, root length, and root diameterof *Pongamia pinnata* seedlings. Table 6.4 represented that the increased of root surfacearea and root volume occur in all growth media except root surface area and root volume in T1, T4, and T8 when reduced the fertilizer rates. T5 contained the highest in root surface area (318.56cm^2), meanwhile T2 demonstrated as the highest of root volume (10.66cm^3) in 50% fertilizer rate compared to other growth media.

Chen et al.(2020) found that root surface area and root volume of Cotton were increased when reduce the fertilizer from 480 kg ha^{-1} N into 240 kg ha^{-1} N. In contrast, T1 containedthe lowest of root surface area (105.85cm^2) and root volume (3.29cm^3) in 50% fertilizer rate compared to other growth media. According to Chen et al. (2020), root surface area and root volume of Cotton were reduced when in 120 kg ha^{-1} N compared to 240 kg ha^{-1} N. Normal root morphology will promote a high crop yield and foundation of nutrient and water uptake by plants. Root length and surface area are appropriate indexes for describing a root system (Amato and Ritchie, 2002). Min et al. (2014) study of drip irrigation with saline water on root length, surface area, volume, and biomass. High concentration of fertilizer suppressed root growth due to saline water irrigation and increased salt stress. According to Razaq et al. (2017), the optimum fertilization level had a favorable impact on root growth. The optimum fertilization rate used significantly increased root elongation that resulted in thegreatest root length, diameter, surface area, and volume, and expected to promote photosynthesis and water potential in leaves (Luo et al., 2014). López-Bucio et al.(2003), Woolfolk and Friend (2003), and Kern et al.(2004) reported that nutrient availability has significant effects on root biomass, production, mortality, root elongation, high root-order development and branching. The optimal fertilization has been shown to enhance root length and root diameter. In contrast, the high and low of fertilizer levels have been shown to reduce root growth and biomass (De Giorgio and Fornaro,2012; Fageria and Moreira,2011); Salih et al.,2005).

Moreover, root elongation was inhibited by either nutrient deficiency or excess of nutrient. Nutrient deficiency can lead to low root activity and water consumption (Zhang et al., 2017) and decrease the production of reactive oxygen species (ROS) in roots (Chen et al., 2018) that resultant in low root biomass accumulation. Nutrient deficiency suppressed root and shoot biomass accumulation because lack of fertilization that resultant in a low of nutrient concentration in growth media, thus a subsequent decline in nutrient uptake (Yang et al., 2013) and inhibiting root elongation. Nutrient deficiency could inhibit shoot growth which in turn could restrict root growth and decrease in yield. Excess of nutrient (especially nitrogen) can increase above ground organ growth and decrease root growth (Zhang et al., 2017). The balance of carbon and N metabolism can be disturbed by high N fertilizer application rates (Hu et al., 2008). Therefore, the transport of photosynthetic products to reproductive organs will decrease under high rates of nutrient application (Zhou et al., 2011). Thus, the balance of vegetative and reproductive growths becomes disrupted due to nutrient excess (Dong et al., 2008). The amount of fertilizer applied significantly affected root morphology and distribution. Chen et al. (2020) reported that the moderate or ideal fertilizer rate improved root growth and increased the total root length, surface area, volume, and biomass.

Table 6.4 : The effect of different growth media on root length, root diameter, root surface area, and root volume in three different fertilizer rates

Growth media	Fertilizer rate	Root Length (cm)	Root Size and Root Diameter (mm)	Distribution Root Surface Area (cm2)	Root Volume (cm3)
T1	100% of fertilizer	310.84±0.11^{e}	1.86±0.07^{ab}	214.65±0.77^{c}	10.00±0.60^{a}
	75% of fertilizer	593.13±12.34^{a}	1.48±0.07^{abc}	122.56±1.83^{e}	4.19±0.11^{e}
	50% of fertilizer	228.04±2.02^{f}	0.97±0.06^{d}	113.20±0.79^{f}	3.44±0.20^{c}
T2	100% of fertilizer	419.65±0.69^{a}	1.11±0.08^{e}	175.95±2.04^{e}	4.87±0.14^{cd}
	75% of fertilizer	398.35±6.38^{e}	1.27±0.07^{c}	184.56±3.41^{c}	5.87±0.26^{c}
	50% of fertilizer	303.37±0.65^{e}	1.73±0.20^{a}	267.60±2.41^{b}	10.66±1.77^{a}
T3	100% of fertilizer	400.21±4.71^{b}	1.71±0.13^{abc}	176.64±1.10^{e}	5.26±0.12^{c}
	75% of fertilizer	434.88±13.74^{d}	1.60±0.14^{bc}	173.69±2.39^{d}	5.52±0.22^{c}
	50% of fertilizer	346.28±1.50^{d}	1.42±0.18^{abc}	230.42±3.11^{d}	8.18±0.09^{b}
T4	100% of fertilizer	320.23±4.81^{e}	1.49±0.21^{bcd}	196.72±4.39^{d}	5.24±0.26^{c}
	75% of fertilizer	505.43±2.27^{b}	1.59±0.10^{a}	120.05±1.71^{e}	4.19±0.18^{e}
	50% of fertilizer	621.00±6.56^{a}	1.23±0.004^{bcd}	116.89±1.53^{f}	3.58±0.04^{c}
T5	100% of fertilizer	346.11±1.74^{d}	1.87±0.09^{a}	245.67±2.99^{a}	6.11±0.09^{b}
	75% of fertilizer	453.38±11.69^{cd}	1.44±0.13^{abc}	305.80±4.38^{a}	8.42±0.26^{a}
	50% of fertilizer	488.04±4.11^{b}	1.27±0.13^{a}	318.56±1.46^{a}	9.61±0.59^{ab}
T6	100% of fertilizer	253.68±1.92^{f}	1.35±0.12^{cde}	142.12±2.75^{f}	3.88±0.08^{ef}
	75% of fertilizer	451.67±9.17^{cd}	1.53±0.02^{abc}	163.59±2.44^{d}	4.97±0.13^{d}
	50% of fertilizer	467.21±7.56^{c}	1.31±0.16^{abcd}	255.62±5.34^{bc}	8.37±1.20^{b}
T7	100% of fertilizer	366.63±2.83^{c}	1.19±0.07^{de}	232.06±2.62^{b}	5.33±0.17^{c}
	75% of fertilizer	461.76±0.84^{c}	1.56±0.07^{ab}	246.48±8.26^{b}	7.34±0.21^{b}
	50% of fertilizer	494.28±8.08^{b}	1.73±0.21^{ab}	248.67±6.50^{c}	9.96±0.12^{ab}
T8	100% of fertilizer	358.98±5.75^{c}	1.41±0.21^{cde}	132.06±3.48^{g}	4.25±0.23^{de}
	75% of fertilizer	516.26±0.10^{b}	1.73±0.10^{a}	121.81±1.71^{e}	4.21±0.09^{e}
	50% of fertilizer	226.40±1.94^{f}	1.08±0.08^{cd}	105.85±1.27^{f}	3.29±0.10^{c}
T9	100% of fertilizer	243.61±1.71^{g}	1.10±0.01^{ab}	110.67±0.59^{h}	3.35±0.18^{f}
	75% of fertilizer	248.17±5.68^{f}	1.53±0.12^{abc}	124.26±3.38^{e}	4.27±0.18^{e}
	50% of fertilizer	310.56±1.91^{e}	1.30±0.19^{abcd}	129.85±7.18^{e}	4.20±0.22^{c}

Means with different letters are significantly different at P≤0.05 using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB.

6.5.4 Dry Matter Production

6.5.4.1 Root Dry Weight, Shoot Dry Weight and Root to Shoot Ratio

The analysis of variance justified the effect of different growth media in three different fertilizer rates were highly significant (P≤0.05) difference on leaf, stem, root dry weight, and root: shoot ratio (Appendix J-n). Appendix J-n also illustrated the leaf, stem, root dry weight, and root: shoot ratio in all growth media were significantly ($P \leq 0.05$) affected by three different fertilizer rates. Table 6.5 represented the leaf, stem, root dry weight, and root: shoot ratio in different growth media in application ofthree different fertilizer rates. Table 6.5 illustrated that the leaf dry weight in all growthmedia were increased except for T1, T3, T4, and T8 when reduced the fertilizer rates. Meanwhile, the stem and root dry weight in all growth media shown in upward trend except for T1, T4, and T8 when reduced the fertilizer rates. Table 6.5 shown that T2 contained the highest of leaf (57.73g) and stem (58.1g) dry weight, meanwhile T5 indicated as the highest of root dry weight with 28.4g in 50% fertilizer rate compared to other growth media.

Oppositely with T8 that contained the lowest of leaf dry weight (15.36g), stem dry weight (16.25g) and root dry weight (4.36g) in 50% fertilizer rate compared to other growth media. From Table 6.5, all growth media shown the increased pattern in root: shoot ratio except for T1, T2, T7 and T8 when decreased the fertilizer rates. The highest of root: shoot ratio (0.39) was in T6, thus contrast with T8 that contained the lowest of root: shoot ratio (0.14) in 50% fertilizer rate compared to other growth media. Baon (2009) found that dry shoot weights of cocoa seedlings were improved by the application of PDAsh. Houba and Keltjens (1990) stated that K nutrient was able indirectly to influence water uptake and improve plant fresh weight. Magnesium and P nutrients dominantly affect leaf weight, whereas other essential nutrients affected stem weight were K and Cu. Those elements essentially function in metabolism processes, such as in protein formation and oxidation-reduction reaction process. Mittra et al. (2005) found that there was a reduction in the use chemical fertilizers by utilizing ash-organic solid mixture. Ichwani and Mapegau (2020) indicated that increased dry weight of maize plant by increased application of coconut husk biochar.

The coconut husk biochar application significantly affected the total dry weight of the plant, and the 15ton ha^{-1} gave the highest total dry weight (Ichwani and Mapegau, 2020). The increase in the total dry weight of maize plant due to various doses of biochar coconut husk is closely related to the increase in leaf area. Potassium (K) plays an important role in the process of photosynthesis by increasing plant growth by increasing CO_2 assimilation and photosynthate translocation (Gardner et al., 1985). Increased growth of maize plants caused by increased K content in plant tissue. Hanudin et al. (2021) also reported that the high fresh and dry root weight was obtained in combination of cow manure with coconut ash. This combination of growth media able to produce better agronomic properties of mustard plant such as fresh shoot weight, dry shoot weight, fresh roots weight, and dry roots weight. Salinity also effect the vegetative dry weight of plant. Lam et al. (2020) found the shoot dry weight (SDW) and root dry weight (RDW) in 4.0 $dS{\cdot}m^{-1}$ treatment was the highest, meanwhile shoot dry weight (SDW) and root dry weight (RDW) at 8 $dS{\cdot}m^{-1}$ were the lowest among all the EC treatments. According to López et al.(2011), Chile pepper root dry weight decreased with increasing soil salinity. Significant decreases in root weight were noted for plants fertilized with 120 kg ha^{-1} inorganic fertilizer and with 200 kg ha^{-1} organic fertilizer as soil salinity levels increased. Only moderate salt-stressed plants showed differences between N rate and source treatments.

Root dry weight decreased in a linear manner in plants fertilized with the high N-organic rate (200 kg ha^{-1}), and in a quadratic manner in plants fertilized with the low N-inorganic rate (120 kg ha^{-1}). Reductions in root and shoot dry matter with increased salinity were also observed in salt-stressed pepper plants by Günes et al. (1996), Kaya and Higgs (2003a), and Kaya and Higgs, (2003b). As stated by Munns (2002), suppression of plant growth under saline conditions may either be due to the decreasing availability of water or to the increasing toxicity of sodium and chloride associated with increasing salinity. As no visual symptoms of salt toxicity such as "salt spots" or necroses were observed, the decreased root and shoot dry weights was apparently due to the accumulation of salts in the soil, which increase the osmotic pressure of the soil solution and greatly decreases the availability of water to the roots. Application of high N rates resulted in increased shoot and root dry weight.

Shoot dry matter was greater than root dry matter. At higher levels of nitrogen supply, shoot growth is greatly stimulated and this in turn decreases the translocation of carbohydrates to the roots, thereby suppressing root growth (Murata, 1969). Leskovar et al. (1989) also found that root and shoot dry weights of pepper plants increased in response to optimum N fertilization. Increased dry mass of the stem of salt-stressed pepper plants related to increased dry mass of leaves was observed by Tadesse et al. (1999). Abou-Hadid et al.(1995) reported that the fresh weight of the three lettuce varieties was decreased with increasing EC level of the nutrient solution. Similar trend was obtained by Charbonneau et al. (1988) who reported that increasing the EC resulted in decrease the vegetative growth of tomato. This result may be interpreted according to Ehret and Ho (1986) who mentioned that at high salinity both the uptake of water by plants and the accumulation of water by plants were reduced. According to Heinen et al.(2001), the fresh weight of tomato reached maximum value at optimum EC, while lowest leaf area at low and high electrical conductivity in nutrient solution. Lam et al. (2020) also found the fresh weights were significantly decreased at low and high ECs of the nutrient solution because of nutrient inadequacy and salinity stress (Ding et al.,2018). Therefore, an excessively low EC of the nutrient solution can lead to nutrient deficiency to plants (not enough supply nutrient for plant growth and yield), while an excessively high EC can lead to salinity stress and ion toxicity (Lam et al.,2020). Bernstein et al. (2013) reported that salinity inhibits growth and development of plant. Inhibition of shoot and root development is the primary response to the stress. The change in root/shoot ratio is often observed when plants are subjected to saline conditions (Cheeseman, 1988; Bernstein et al., 2004; Perica et al., 2008; Khayyat et al., 2009). The restriction of root growth by salinity, which reduces the soil volume that can be explored by the root and hence the availability and uptake of water and essential minerals, diminishes the supply of nutrients to the shoot which may contribute to growth reduction (Lazof and Bernstein, 1998). The increase in root/shoot ratio reduces the demand for element supply to the shoot and thereby has a potential to increase the ability of the root to supply those elements and present an adaptive advantage (Cheeseman, 1988).

Table 6.5 : The effect of different growth media on leaf, stem, root dry weight, and root: shoot ratio in different fertilizer rates

Growth media	Fertilizer rate	Leaf (g)	Stem (g)	Root (g)	Root : Shoot
	Dry Matter Production				
T1	100% of fertilizer	54.37 ± 2.87^{a}	60.03 ± 1.29^{a}	23.25 ± 0.82^{a}	0.20 ± 0.01^{cd}
	75% of fertilizer	36.39 ± 1.48^{b}	23.1 ± 0.75^{d}	12.29 ± 0.40^{bc}	0.21 ± 0.00^{de}
	50% of fertilizer	17.06 ± 2.16^{fg}	18.23 ± 0.54^{f}	5.41 ± 0.82^{f}	0.15 ± 0.02^{f}
T2	100% of fertilizer	25.54 ± 1.50^{d}	22.08 ± 1.18^{cd}	12.83 ± 0.97^{b}	0.27 ± 0.02^{ab}
	75% of fertilizer	36.27 ± 1.45^{b}	38.32 ± 1.12^{b}	14.13 ± 0.98^{b}	0.19 ± 0.01^{e}
	50% of fertilizer	57.73 ± 1.78^{a}	58.1 ± 0.68^{a}	25.33 ± 0.27^{b}	0.22 ± 0.00^{e}
T3	100% of fertilizer	34.21 ± 0.75^{c}	22.16 ± 1.32^{cd}	13.57 ± 0.40^{b}	0.24 ± 0.01^{abcd}
	75% of fertilizer	30.84 ± 0.70^{c}	24.89 ± 0.43^{c}	13.13 ± 0.92^{b}	0.24 ± 0.01^{bcd}
	50% of fertilizer	32.06 ± 0.95^{c}	26.84 ± 0.49^{d}	18.4 ± 0.47^{d}	0.31 ± 0.01^{b}
T4	100% of fertilizer	35.71 ± 0.57^{c}	23.37 ± 0.86^{c}	12.05 ± 0.38^{b}	0.20 ± 0.00^{cd}
	75% of fertilizer	32.46 ± 0.50^{c}	22.11 ± 0.47^{d}	13.57 ± 1.29^{b}	0.25 ± 0.03^{abcd}
	50% of fertilizer	26.88 ± 1.72^{d}	18.95 ± 0.49^{f}	9.84 ± 0.29^{e}	0.21 ± 0.01^{e}
T5	100% of fertilizer	42.78 ± 2.52^{b}	41.33 ± 0.71^{b}	22.23 ± 1.69^{a}	0.26 ± 0.02^{ab}
	75% of fertilizer	43.13 ± 1.09^{a}	41.52 ± 0.57^{a}	22.87 ± 0.26^{a}	0.27 ± 0.01^{ab}
	50% of fertilizer	49.19 ± 2.09^{b}	43.91 ± 0.41^{b}	28.4 ± 0.55^{a}	0.31 ± 0.01^{bc}
T6	100% of fertilizer	24.25 ± 0.88^{d}	21.26 ± 1.89^{cd}	11.25 ± 0.99^{b}	0.25 ± 0.02^{abc}
	75% of fertilizer	27.83 ± 0.27^{d}	21.56 ± 0.52^{d}	12.40 ± 1.45^{bc}	0.25 ± 0.03^{abc}
	50% of fertilizer	24.92 ± 1.09^{de}	22.52 ± 0.52^{e}	18.62 ± 1.00^{d}	0.39 ± 0.02^{a}
T7	100% of fertilizer	38.50 ± 2.42^{bc}	39.18 ± 2.82^{b}	21.62 ± 0.94^{a}	0.28 ± 0.03^{a}
	75% of fertilizer	40.78 ± 1.20^{a}	39.41 ± 0.43^{b}	22.72 ± 0.90^{a}	0.28 ± 0.01^{a}
	50% of fertilizer	47.79 ± 1.75^{b}	41.28 ± 0.64^{c}	23.88 ± 0.51^{c}	0.27 ± 0.00^{cd}
T8	100% of fertilizer	28.83 ± 0.92^{d}	20.42 ± 0.95^{cd}	11.02 ± 0.89^{b}	0.22 ± 0.02^{bcd}
	75% of fertilizer	23.59 ± 0.35^{e}	19.39 ± 0.72^{e}	10.92 ± 0.49^{c}	0.25 ± 0.01^{abc}
	50% of fertilizer	15.36 ± 1.27^{g}	16.25 ± 0.20^{g}	4.36 ± 0.90^{f}	0.14 ± 0.02^{f}
T9	100% of fertilizer	17.36 ± 1.01^{e}	18.17 ± 1.15^{d}	7.24 ± 0.12^{c}	0.20 ± 0.01^{d}
	75% of fertilizer	19.92 ± 0.14^{f}	18.24 ± 0.74^{e}	8.19 ± 0.75^{d}	0.21 ± 0.02^{cde}
	50% of fertilizer	21.62 ± 0.64^{ef}	19.42 ± 0.22^{f}	9.97 ± 0.20^{e}	0.24 ± 0.00^{de}

Means with different letters are significantly different at $P \leq 0.05$ using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB.

6.5.5 Nutrient Content of Fruit

Appendix J-o illustrated the analysis of variance of nutrient content and C:N ratio in harvested fruit showed significant ($P \leq 0.05$) affected by different growth media. Meanwhile, Appendix J-o also justify that the nutrient content of C, N, S, P, K, Ca, Fe, Mg, Zn, Al, Mn, Na and C:N ratio in harvested fruit showed significant ($P \leq 0.05$) differences by application of different fertilizer rates. Table 6.6 shown the nutrient content in harvested chilli fruit by application of 100%, 75%, and 50% of fertilizer rates. The concentration of Na in harvested fruit that grown in all grown media were decreased when reducing the fertilizer rates due to decreased of salinity (electrical conductivity) in growth media. Nutrient uptake and transport may be affected by the simultaneous presence of salts and application of nutrient elements (Alam, 1999). High concentration of Na in growth media are taken up at high rates by plants, which may lead to excessive accumulation in the tissue (Cramer et al., 1991). Ondrasek et al.(2021) found that highest concentration of Na (7.10g/kg) in strawberry fruits after application of 60 mM NaCl compared with Na concentration with 2.0g/kg in strawberry fruits after application of 20 mM NaCl.

Ondrasek et al.(2021) also reported that the rising soil salinity (electrical conductivity) significantly enhanced Na and Cl accumulation in strawberry leaves and fruits. According to Semiz et al.(2014), the Na content in pepper (*Capsicum annuum* L.) was affected only by salinity level. Increasing salinity level in the soil water led to an increase in the Na content of the pepper (*Capsicum annuum* L.) at the high salinity growth media and increase of fertilizer rates (Semiz et al.,2014). In addition, the increasing irrigation water salinity (EC) led to an increase in Na^+ uptake by nongrafted eggplant fruit (Semiz and Suarez, 2019). Table 6.6 illustrated that all nutrient content in harvested fruit grown in T1 were decreased when decreased of fertilizer rates except concentration of Al, Mn, and C:N ratio.

Similar with nutrient content in harvested fruit growth in T4 that resultant in declined pattern when decreased of fertilizer application except Al, Mn, and Ca contents. Table 6.6 shown that the decreased of C, N, S, P, K, Mg content occur in harvested fruit grown in T8 in reduced the fertilizer rates. Meanwhile, the most nutrient content in harvested fruit grown in T2 were increased except Fe, Al, Mn and C:N ratio when reducing the fertilizer rates. All nutrient content in harvested fruit in T3 were rose when decreased of fertilizer rates except Mn and C:N ratio. Table 6.6 also illustrated that T5 contained increased of nutrient content in harvested fruit when reduced the fertilizer rates except for Al, Mn and C:N ratio. Meanwhile, T6 incurred in decreased of Zn, Al, Mn and C:N ratio in harvested fruit when reduced of fertilizer rates. Most of nutrient content in harvested fruit grown in T7 were increased when decreased of fertilizer rate, however Mn content shown in decreased pattern when reduced of fertilizer rates. Moreover, the harvested fruit in T9 contained the declined concentration of Fe, and C:N ratio when fertilizer rates was reduced, meanwhile the other nutrient shown increased pattern in nutrient content of harvested chilli fruit grown in T9. However, the harvested fruit in all growth media contained less than or equal to 0.01mg/l of nutrient content as refer to Table 6.6. It indicates that pepper growth and nutrient absorption (uptake) effected by pH and salinity in growth media (Malkanthi et al.,1995; Supanjani and Lee,2006; Ahmadi and Souri,2019).

pH is a measure of the hydrogen ions present in the nutrient medium readily available for plant uptake (Beede et al.,2005). The pH in growth media has a significant effect on nutrient availability. The suitable pH in growth media for pepper growth is 5.5 to 7.0 (Yang et al.,2009). High pH greatly limits the solubility of many elements such as Zn, Cu, Mn, Fe, while low pH can lead to deficiencies of P or Ca and toxicities of Al, Fe or Mn. In general, determination of pH in growth media can aid in the diagnosis of nutrient deficiencies (Beede et al.,2005). pH affects the availability of mineral nutrients for plant growth. Low pH (less than 5.5) may result in deficiencies of Ca, Mg, P or Mo and perhaps excesses of Mn, Fe or Al (Beede et al.,2005). Neina (2019) also reported that soil pH values less than 5.5 suggest the possible presence of toxic levels of soil aluminum. High pH (more than 7.5) may immobilize Mn, Zn, Fe or Cu, and unavailable to the plant. Moreover, high levels of calcium carbonate (lime) in the soil can induce deficiencies of Fe, Mn or Zn and may also make acidification of the growth media difficult (Beede et al.,2005). In highly acidic growth media, aluminum and manganese can become more available and more toxic to plant while calcium, phosphorus, and magnesium are less available to the plant.

In highly alkaline growth media, phosphorus and most micronutrients become less available. In addition, pepper grown in low pH often showed poor growth, serious plant diseases and insect pests, nutrient deficiency, low yield and poor quality (Zu et al.,2014). Fertilization improve plant growth and production (Noulas et al.,2004). However, the excess application of fertilizer rate has been reported to mitigate significantly the adverse effects caused by high salt stress on a number of plants (Leidi et al.,1991; Song et al.,2006). Water deficit and salt-specific or ion-excess affected by salinity are the main reasons which inhibit plant growth (Munnset et al.,2006). Pepper (*Capsicum annuum* L.) is classified as a moderately sensitive crop (Maas and Hoffman, 1977), and some adverse effects of salinity on macronutrient content in its different plant parts have been reported (Chartzoulakis and Klapaki, 2000; De Pascale et al., 2003; Navarro et al., 2003). The negative effect of salinity on plant growth and development may be the result of reduced water and nutrient uptake. Salt uptake competes with the uptake of other nutrient ions, such as K^+, Ca^{2+}, N, P resulting in nutritional disorders and eventually, reduced yield and quality (Grattan and Grieve, 1998). The eggplant fruit Ca^{2+} content decreased with salinity (Semiz and Suarez,2019). Therefore, Wang et al. (2015) also suggested that a moderate fertilizer application rate (210 kgN ha^{-1}) in wheat fields could increase the uptake of soil-N and decrease NO_3-N leaching under supplemental irrigation. It also results in nutritional imbalances. Salinity in growth media significantly reduces phosphorus uptake by plants because phosphate ions precipitate with Ca ions which is detrimental for plant growth (Bano and Fatima, 2009). Salinity also imposes ion toxicity, osmotic stress, nutrient (N, Ca, K, P, Fe, Zn) deficiency and oxidative stress on plants, and thus limits water uptake from growth media. Moreover, salinity in growth media significantly reduces plant phosphorus (P) uptake because phosphate ions precipitate with Ca ions (Bano and Fatima, 2009).

Under low salinity stress, nutrient deficiency limits plant growth more than salinity and a positive interaction or an increased salt tolerance response occurs (Esmaili et al.,2008). In recent years, strategies have been proposed to reduce fertilizer inputs to an appropriate level that exactly satisfies a crop's needs (McSwiney and Robertson, 2005). Thus, Liu et al. (2014) found that a lower application rate (110kgN ha^{-1}) for maize on ridges and furrows mulched with plastic-film system obtained 82% of the maximum yield, increased the nitrogen use efficiency (NUE), and mitigated the risk of nitrogen losses from the system. Therefore, the optimal fertilizer application rate should be determined based on analyses of soil residual nutrients to achieve superior crop yields and use resources efficiently.

Table 6.6 : The nutrient content of harvested fruit in different growth media by applied three different fertilizer rates

Growth media	Fertilizer	Element					
		C(%)	N(%)	C/N	S(%)	P(mg/l)	K(mg/l)
T1	100% of fertilizer	30.43±0.040^{d}	0.40±0.006^{a}	76.09±0.98^{h}	0.08±0.004^{a}	18.30±0.020^{b}	18.80±0.15^{f}
	75% of fertilizer	18.56±0.020^{i}	0.34±0.002^{b}	54.59±0.35^{i}	0.06±0.002^{b}	17.90±0.046^{b}	13.70±0.092^{i}
	50% of fertilizer	22.08±0.020^{h}	0.21±0.003^{h}	105.16±1.60^{d}	0.04±0.003^{d}	11.30±0.020^{h}	12.86±0.072^{i}
T2	100% of fertilizer	23.15±0.020^{i}	0.26±0.003^{d}	88.93±0.92^{g}	0.04±0.003^{d}	12.50±0.010^{e}	30.59±0.11^{c}
	75% of fertilizer	28.7±0.017^{f}	0.36±0.002^{a}	79.72±0.36^{h}	0.08±0.002^{a}	15.20±0.020^{d}	30.68±0.070^{b}
	50% of fertilizer	35.37±0.020^{c}	0.48±0.002^{a}	73.69±0.23^{f}	0.08±0.003^{a}	18.20±0.040^{c}	30.94±0.13b
T3	100% of fertilizer	32.39±0.052^{c}	0.20±0.002^{g}	161.69±1.52^{b}	0.02±0.003^{f}	14.90±0.050c	15.54±0.052g
	75% of fertilizer	43.11±0.030^{a}	0.30±0.003^{d}	143.55±1.48^{c}	0.06±0.003^{b}	16.40±0.010c	17.56±0.14f
	50% of fertilizer	37.06±0.020^{b}	0.30±0.003^{d}	123.54±1.30^{c}	0.05±0.002^{c}	21.80±0.020b	22.08±0.072d
T4	100% of fertilizer	27.33±0.040^{f}	0.38±0.003^{b}	71.86±0.65^{i}	0.05±0.002^{c}	12.20±0.020f	21.37±0.085e
	75% of fertilizer	23.56±0.046^{h}	0.22±0.004^{g}	107.11±1.56^{e}	0.03±0.004^{d}	10.40±0.010h	19.18±0.066e
	50% of fertilizer	19.13±0.017^{i}	0.26±0.003^{g}	73.58±0.71^{f}	0.03±0.002^{e}	9.96±0.002i	14.97±0.069g
T5	100% of fertilizer	26.14±0.020^{g}	0.28±0.002^{c}	93.36±0.58^{f}	0.06±0.004^{b}	13.00±0.030d	30.92±0.11b
	75% of fertilizer	28.5±0.040^{g}	0.32±0.004^{c}	89.07±1.24^{g}	0.04±0.002^{d}	13.30±0.020f	31.50±0.12a
	50% of fertilizer	33.27±0.020^{f}	0.38±0.002^{b}	87.55±0.36^{e}	0.06±0.003^{b}	16.80±0.010d	33.70±0.12a
T6	100% of fertilizer	25.06±0.020^{h}	0.25±0.003^{e}	100.25±1.37^{e}	0.03±0.002^{e}	20.10±0.020a	10.34±0.10h
	75% of fertilizer	31.63±0.017^{e}	0.32±0.002^{c}	98.85±0.48^{f}	0.05±0.003^{c}	20.60±0.017a	16.58±0.095g
	50% of fertilizer	30.55±0.036^{g}	0.35±0.002^{c}	87.29±0.47^{e}	0.05±0.004^{c}	24.80±0.017a	17.33±0.056f
T7	100% of fertilizer	28.62±0.017^{e}	0.23±0.002^{f}	124.44±1.02^{d}	0.03±0.002^{e}	10.30±0.017g	15.61±0.040g
	75% of fertilizer	32.17±0.020^{d}	0.26±0.003^{e}	123.74±1.33^{d}	0.06±0.003^{b}	9.27±0.017i	16.28±0.080h
	50% of fertilizer	35.00±0.017^{d}	0.28±0.003^{e}	125.01±1.14^{c}	0.05±0.002^{c}	12.57±0.003f	17.65±0.092e
T8	100% of fertilizer	36.70±0.030^{a}	0.28±0.003^{c}	131.08±1.27^{c}	0.06±0.003^{b}	13.00±0.040d	31.85±0.082a
	75% of fertilizer	33.24±0.020^{c}	0.21±0.001^{h}	158.29±0.66^{b}	0.05±0.003^{c}	12.20±0.030g	23.45±0.12c
	50% of fertilizer	34.53±0.050^{e}	0.18±0.004^{i}	191.53±3.81^{a}	0.03±0.004^{e}	12.00±0.030g	14.22±0.060h
T9	100% of fertilizer	34.81±0.040^{b}	0.17±0.002^{h}	204.78±1.90^{a}	0.009±0.001^{g}	9.00±0.020h	23.32±0.15d
	75% of fertilizer	38.26±0.035^{b}	0.23±0.002^{f}	166.36±1.32^{a}	0.02±0.002^{e}	13.40±0.010e	22.21±0.050d
	50% of fertilizer	43.38±0.020^{a}	0.27±0.003^{f}	160.68±1.51^{b}	0.04±0.003^{d}	15.40±0.017e	29.99±0.19c

Table 6.6: Continued

Growth media	Fertilizer	Element			
		Ca(mg/l)	Fe(mg/l)	Mg(mg/l)	Zn(mg/l)
T1	100% of fertilizer	26.03 ± 0.044^{b}	2.34 ± 0.001^{d}	16.81 ± 0.030^{f}	0.16 ± 0.002^{g}
	75% of fertilizer	22.2 ± 0.046^{h}	1.08 ± 0.009^{i}	16.78 ± 0.017^{g}	0.16 ± 0.002^{g}
	50% of fertilizer	21.48 ± 0.020^{i}	1.06 ± 0.001^{i}	13.55 ± 0.010^{i}	0.14 ± 0.001^{h}
T2	100% of fertilizer	21.46 ± 0.010^{f}	9.93 ± 0.002^{a}	19.51 ± 0.010^{d}	0.19 ± 0.003^{e}
	75% of fertilizer	30.65 ± 0.005^{d}	1.48 ± 0.001^{h}	24.77 ± 0.017^{d}	0.21 ± 0.003^{e}
	50% of fertilizer	102.10 ± 0.030^{b}	1.53 ± 0.002^{g}	74.55 ± 0.020^{b}	1.22 ± 0.002^{a}
T3	100% of fertilizer	17.06 ± 0.050^{i}	1.74 ± 0.002^{f}	9.895 ± 0.002^{i}	0.13 ± 0.001^{h}
	75% of fertilizer	15.69 ± 0.010^{i}	4.87 ± 0.001^{a}	13.25 ± 0.010^{h}	0.23 ± 0.003^{d}
	50% of fertilizer	27.87 ± 0.010^{h}	9.90 ± 0.009^{a}	45.94 ± 0.010^{e}	0.79 ± 0.001^{e}
T4	100% of fertilizer	24.46 ± 0.020^{d}	4.86 ± 0.003^{c}	51.49 ± 0.017^{a}	0.70 ± 0.003^{a}
	75% of fertilizer	28.85 ± 0.010^{f}	1.52 ± 0.002^{g}	18.29 ± 0.017^{f}	0.17 ± 0.001^{f}
	50% of fertilizer	90.44 ± 0.017^{d}	1.35 ± 0.001^{h}	16.27 ± 0.010^{g}	0.15 ± 0.002^{h}
T5	100% of fertilizer	27.23 ± 0.030^{a}	1.65 ± 0.002^{g}	22.19 ± 0.017^{c}	0.18 ± 0.001^{f}
	75% of fertilizer	37.96 ± 0.010^{a}	1.60 ± 0.001^{f}	34.29 ± 0.010^{a}	0.21 ± 0.002^{e}
	50% of fertilizer	105.40 ± 0.020^{a}	7.31 ± 0.006^{b}	82.58 ± 0.020^{a}	0.92 ± 0.003^{c}
T6	100% of fertilizer	17.18 ± 0.020^{h}	1.39 ± 0.005^{h}	17.12 ± 0.010^{e}	0.55 ± 0.001^{b}
	75% of fertilizer	30.28 ± 0.005^{e}	3.77 ± 0.001^{b}	11.59 ± 0.017^{g}	0.33 ± 0.002^{b}
	50% of fertilizer	50.61 ± 0.010^{g}	4.82 ± 0.002^{c}	38.74 ± 0.010^{f}	0.46 ± 0.002^{g}
T7	100% of fertilizer	19.97 ± 0.020^{g}	0.98 ± 0.001^{i}	15.84 ± 0.017^{h}	0.16 ± 0.002^{g}
	75% of fertilizer	24.19 ± 0.060^{g}	2.63 ± 0.001^{e}	26.05 ± 0.020^{c}	0.40 ± 0.003^{a}
	50% of fertilizer	98.79 ± 0.030^{c}	3.05 ± 0.001^{f}	56.44 ± 0.005^{d}	0.87 ± 0.002^{d}
T8	100% of fertilizer	25.23 ± 0.020^{c}	1.76 ± 0.003^{e}	49.55 ± 0.020^{b}	0.20 ± 0.002^{d}
	75% of fertilizer	37.12 ± 0.010^{b}	3.70 ± 0.001^{c}	23.24 ± 0.010^{e}	0.24 ± 0.004^{c}
	50% of fertilizer	66 ± 0.010^{f}	4.43 ± 0.003^{e}	15.5 ± 0.011^{h}	0.76 ± 0.002^{f}
T9	100% of fertilizer	23.74 ± 0.010^{e}	7.19 ± 0.001^{b}	16.22 ± 0.010^{g}	0.25 ± 0.001^{c}
	75% of fertilizer	32.96 ± 0.010^{c}	3.34 ± 0.001^{d}	27.31 ± 0.017^{b}	0.40 ± 0.002^{a}
	50% of fertilizer	86.42 ± 0.020^{e}	4.78 ± 0.001^{d}	60.76 ± 0.010^{c}	1.01 ± 0.008^{b}

Table 6.6: Continued

Growth media	Fertilizer	Element			
		Al(mg/l)	Mn(mg/l)	Na(mg/l)	Other
T1	100% of fertilizer	0.91 ± 0.003^{e}	0.08 ± 0.010^{g}	9.91 ± 0.002^{d}	≤0.01
	75% of fertilizer	1.19 ± 0.002^{g}	0.26 ± 0.002^{d}	5.26 ± 0.004^{h}	≤0.01
	50% of fertilizer	1.42 ± 0.004^{f}	0.44 ± 0.001^{b}	2.99 ± 0.001^{i}	≤0.01
T2	100% of fertilizer	5.44 ± 0.002^{a}	0.81 ± 0.001^{a}	11.06 ± 0.01	≤0.01
	75% of fertilizer	2.31 ± 0.003^{a}	0.11 ± 0.001^{g}	7.41 ± 0.003^{a}	≤0.01
	50% of fertilizer	1.04 ± 0.005^{g}	0.07 ± 0.002^{h}	6.52 ± 0.002^{b}	≤0.01
T3	100% of fertilizer	0.38 ± 0.006^{h}	0.47 ± 0.000^{d}	9.78 ± 0.040^{e}	≤0.01
	75% of fertilizer	0.54 ± 0.001^{i}	0.33 ± 0.001^{b}	5.95 ± 0.002^{d}	≤0.01
	50% of fertilizer	2.37 ± 0.001^{fd}	0.10 ± 0.002^{f}	4.41 ± 0.001^{f}	≤0.01
T4	100% of fertilizer	0.73 ± 0.005^{f}	0.002 ± 0.000^{h}	8.98 ± 0.010^{g}	≤0.01
	75% of fertilizer	1.46 ± 0.003^{e}	0.01 ± 0.002^{i}	5.61 ± 0.001^{f}	≤0.01
	50% of fertilizer	5.42 ± 0.000^{a}	0.08 ± 0.002^{g}	3.62 ± 0.002^{g}	≤0.01
T5	100% of fertilizer	2.09 ± 0.004^{c}	0.60 ± 0.002^{c}	10.24 ± 0.02	≤0.01
	75% of fertilizer	1.01 ± 0.002^{h}	0.13 ± 0.003^{f}	6.67 ± 0.002^{b}	≤0.01
	50% of fertilizer	0.73 ± 0.001^{h}	0.04 ± 0.002^{i}	5.68 ± 0.001^{d}	≤0.01
T6	100% of fertilizer	4.70 ± 0.004^{b}	0.43 ± 0.005^{e}	10.95 ± 0.001^{b}	≤0.01
	75% of fertilizer	1.91 ± 0.004^{c}	0.31 ± 0.001^{c}	4.31 ± 0.001^{i}	≤0.01
	50% of fertilizer	0.56 ± 0.002^{i}	0.26 ± 0.001^{e}	5.99 ± 0.005^{c}	≤0.01
T7	100% of fertilizer	0.64 ± 0.002^{g}	0.61 ± 0.002^{b}	9.35 ± 0.010^{f}	≤0.01
	75% of fertilizer	1.59 ± 0.003^{d}	0.58 ± 0.003^{a}	5.92 ± 0.003^{e}	≤0.01
	50% of fertilizer	1.65 ± 0.001^{e}	0.51 ± 0.009^{a}	5.56 ± 0.002^{e}	≤0.01
T8	100% of fertilizer	0.91 ± 0.004^{e}	0.01 ± 0.001^{h}	8.55 ± 0.017^{h}	≤0.01
	75% of fertilizer	1.26 ± 0.001^{f}	0.05 ± 0.001^{h}	5.35 ± 0.001^{g}	≤0.01
	50% of fertilizer	5.30 ± 0.000^{b}	0.33 ± 0.001^{d}	3.02 ± 0.003^{h}	≤0.01
T9	100% of fertilizer	1.01 ± 0.002^{d}	0.15 ± 0.004^{f}	6.11 ± 0.01	≤0.01
	75% of fertilizer	1.96 ± 0.002^{b}	0.16 ± 0.003^{e}	6.51 ± 0.002^{c}	≤0.01
	50% of fertilizer	3.68 ± 0.001^{c}	0.43 ± 0.005^{c}	6.69 ± 0.001^{a}	≤0.01

Means with different letters are significantly different at $P \leq 0.05$ using Tukey's Studentized Range (HSD). Columns refer to T1=CCD, T2=CSA, T3=PKSB, T4=3CCD :1 CSA, T5=2CCD :1 CSA, T6=1CCD :1 CSA, T7=3CCD :1PKSB, T8=2CCD :1PKSB, T9=1CCD :1PKSB.

6.6 Cost-Benefit

A structure of costs and revenue were estimation utilized for 1,000 polybag of recommended growth media applied with three different fertilizer rates. The recommended growth media were selected by plant production after harvesting. The net benefit was obtained as the difference between the total income and total costs (Cámara-Zapata et al., 2019). Thus, the benefit cost was determined by percentage between the net benefit and total costs. Table 6.7 to Table 6.11 represented the benefit cost of 1,000 polybag of recommended growth media applied with three different fertilizer rates. The highest benefit cost ratio (1.15) was found in T2 applied with 50% fertilizer rate, followed T5 applied with 50% fertilizer rate with benefit cost ratio of 0.80 by refer to Table 6.9 and Table 6.10 compared to other recommended growth media. Growth media T2 applied with 50% fertilizer rate able to increase 11% of revenue (RM11,200.00) compared to revenue of growth media T1 applied with 100% fertilizer (RM 10,100.00). Meanwhile, Table 6.7 and Table 6.10 illustrated growth media T5 applied with 50% fertilizer rate resultant in same revenue and increased 14% of benefit cost ratio (0.80) compared with T1 applied with 100% fertilizer rate (0.70). It is due to growth media T2 and T5 applied with 50% fertilizer rate able to minimize expenses in raw material of growth media and fertilizer costs. The higher the benefit cost ratio (BCR) indicate the more attractive the risk-return profile of the project or cultivation. Bheel et al. (2021) reported the use of CSA reduce the raw material cost due CSA is product of agriculture waste and low cost (cheaper than CCD) thus affected the benefit cost ratio (BCR). Further, growth media T2 and T5 able to reduced by 50% fertilizer cost by supply half (50% fertilizer rate) from standard rate of fertilizer (100% fertilizer rate on chilli) while provide the enough nutrient to enhance the plant production, protect the environment and human health (Silva et al.,2000; Chandini et al.,2019). Therefore, growth media T2 (100% CSA) and T5 (2CCD:1CSA) were highly recommended to apply as a new soilless growth and minimize the chemical fertilizer use cost.

Table 6.7 : The benefit cost of 1,000 polybag of recommended growth media T1 (100% coconut coir dust) applied with F1 (100% fertilizer rate)

Item	Quantity	Price per unit (RM)	Total (RM)
A) Cost/Expenses			
I. Input Cost			
1) Growth media	1,000	RM1.40/polybeg	**1,400.00**
(2kg/polybag)			
2) Chilli seed	1	60	**60**
3) Fertilizer (4 months)	4	150/set	**600**
4) Insecticide/Pesticide	2	30	**60**
5) Weedicide (4L)	1	30	**30**
II. Labour and Operation			
Cost			
1) Site preparation	1	700.00 x 1 time	**700**
2) Planting	2	50.00 x 1 time	**100**
3) Weeding	1	50.00 x 2 times	**100**
4) Spraying insecticide/pesticide	1	50.00 x 8 times	**400**
5) Harvesting	3	50.00 x 1 time	**150**
6) Electricity & water cost	1	500.00 x 4	**2,000.00**
		months	
III. Fixed Cost			
1) Land rental	1	500	**500**
Total Cost (A)	**RM6,100.00**		
B) Return (Input)			
Fresh yield	1,000plant	RM10.00/kg	**10,000.00**
(yield per plant = 1.01kg)			
			10,100.00
Total Return (B)			
C) Net Benefit (B-A)			
D) Benefit Cost			**RM4,000.00**

Table 6.8 : The benefit cost of 1,000 polybag of recommended growth media T5 (2 coconut coir dust : 1 coconut shell ash) applied with F2 (75% fertilizer rate)

Item	Quantity	Price per unit (RM)	Total (RM)
A) Cost/Expenses			
I. Input Cost			
1) Growth media	1,000	RM	1,200.00
(3kg/polybag)		1.20/polybeg	
2) Chilli seed	1	60	60
3) Fertilizer (4 months)	4	112.5/set	450
4) Insecticide/Pesticide	2	30	60
5) Weedicide (4L)	1	30	30
II. Labour and Operation Cost			
1) Site preparation	1	700.00 x 1 time	700
2) Planting	2	50.00 x 1 time	100
3) Weeding	1	50.00 x 2 times	100
4) Spraying insecticide/pesticide	1	50.00 x 8 times	400
5) Harvesting	3	50.00 x 1 time	150
6) Electricity & water cost	1	500.00 x 4	2,000.00
		months	
III. Fixed Cost			
1) Land rental		500	500
Total Cost (A)	**RM5,750.00**		
B) Return (Input)			
Fresh yield	)0plant (yield per plant = 0.81kg)		
RM10.00/kg	RM8,100.00		
Total Return (B)	**RM8,100.00**		
C) Net Benefit (B-A)			
D) Benefit Cost			
RM2,350.00			
0.41			

Table 6.9 : The benefit cost of 1,000 polybag of recommended growth media T2 (100% coconut shell ash) applied with F3 (50% fertilizer rate)

Item	Quantity	Price per unit (RM)	Total (RM)
Cost/Expenses			
Input Cost			
1) Growth media (4kg/polybeg)	1,000	RM 0.80/	800
		polybeg	
2) Chilli seed	1	60	60
3) Fertilizer (4 months)	4	75/set	300
4) Insecticide/Pesticide	2	30	60
5) Weedicide (4L)	1	30	30
Labour and Operation Cost			
1) Site preparation	1	700.00 x 1 time	700
2) Planting	2	50.00 x 1 time	100
3) Weeding	1	50.00 x 2 times	100
4) Spraying insecticide/pesticide	1	50.00 x 8 times	400
5) Harvesting	3	50.00 x 1 time	150
6) Electricity & water cost	1	500.00 x 4	2,000.00
		months	
		500	500
			RM5,200.00
		RM10.00/kg	RM11,200.00
Total Return (B)			**RM11,200.00**
C)			
Net Benefit (B-A)			
D) Benefit Cost			
RM6,000.00			
1.15			

Table 6.10 : The benefit cost of 1,000 polybag of recommended growth media T5 (2 coconut coir dust : 1 coconut shell ash) applied with F3 (50% fertilizer rate)

Item	Quantity	Price per unit (RM)	Total (RM)
Cost/Expenses			
Input Cost			
1) Growth media (3kg/polybeg)	1,000	RM	1,200.00
		1.20/polybeg	
2) Chilli seed	1	60	60
3) Fertilizer (4 months)	4	75/set	300
4) Insecticide/Pesticide	2	30	60
5) Weedicide (4L)	1	30	30
Labour and Operation Cost			
1) Site preparation	1	700.00 x 1 time	700
2) Planting	2	50.00 x 1 time	100
3) Weeding	1	50.00 x 2 times	100
4) Spraying insecticide/pesticide	1	50.00 x 8 times	400
5) Harvesting	3	50.00 x 1 time	150
6) Electricity & water cost	1	500.00 x 4	2,000.00
III. Fixed Cost			
1) Land rental 1		500	500
Total Cost (A)			**RM5,600.00**
B) Return (Input)			
Fresh yield 1,000plant		RM10.00/kg	RM10,100.00
(yield per plant = 1.01kg)			
Total Return (B)			**RM10,100.00**
C) Net Benefit (B-A)			**RM4,500.00**
D) Benefit Cost			**0.8**

Table 6.11 : The benefit cost of 1,000 polybeg of recommended growth media T7 (3 coconut coir dust : 1 palm kernel shell biochar) applied with F3 (50% fertilizer rate)

Item	Quantity	Price per unit (RM)	Total (RM)
Cost/Expenses			
Input Cost			
1) Growth media (3kg/polybeg)	1,000	RM 4.50/polybeg	4,500.00
2) Chilli seed	1	60	60
3) Fertilizer (4 months)	4	75/set	300
4) Insecticide/Pesticide	2	30	60
5) Weedicide (4L)	1	30	30
Labour and Operation Cost			
1) Site preparation	1	700.00 x 1 time	700
2) Planting	2	50.00 x 1 time	100
3) Weeding	1	50.00 x 2 times	100
4) Spraying insecticide/pesticide	1	50.00 x 8 times	400
5) Harvesting	3	50.00 x 1 time	150
6) Electricity & water cost	1	500.00 x 4 months	2,000.00
III. Fixed Cost			
1) Land rental 1		500	500
Total Cost (A)			**RM8,900.00**
B) Return (Input)			
Fresh yield 1,000plant (yield per plant = 1.01kg)		RM10.00/kg	RM10,100.00
Total Return (B)			**RM10,100.00**
C) Net Benefit (B-A)			**RM1,200.00**
D) Benefit Cost			**0.14**

6.7 Conclusion

From this experiment, T2 (100% CSA) and growth media T5 (2CCD:1CSA) were the best growth media that have increased the plant height, stem diameter, total leaf area, chlorophyll content, short day to initiate the flowering, number and weight of yields, fruit nutrient uptakes, root size and distributions, and total dry weight of *Capsicum annuum L. Var. Kulai* by reducing 50% of standard chemical fertilizer rate for chilli due to decreasing of the salinity(EC) in growth media and reached the optimum balance condition for plant growth and development by increased the pH, electrical conductivity, cation-exchangeable capacity, exchangeable cations, as well as high in macronutrient and micronutrient contents. The application of optimum dose of fertilizer and nutrient supply is important to increase the pepper growth, development and maximize the yield of pepper. Moreover, T2 (100% CSA) and T5 (2CCD:1CSA) able to increase the benefit cost ratio (BCR) by minimize the raw material and fertilizer use cost. The pH, salinity andCEC in growth media influence the nutrient availability, water uptake, biological activityand solubility of aluminum and iron ions, and acidification, thus effect the plant vegetativeand yield productions (Gurmessa,2021). However, the reduce of fertilizer rate causes stunted of growth and reduce the crop's yield in T1(100% CCD), and combination growthmedia T4(3CCD:1CSA), and T8(2CCD:1PKSB) were due to deficiency of nutrient supplyfor plant growth and productions (Uchida,2000; Heinen et al.,2001). Moreover, the decrease of pH (acidic) and CEC occur when reduce the fertilizer rate will disturb the nutrient availability, mobility, and imbalance the uptake of water and nutrients for crops. Therefore, the application of 100% coconut ash and growth media of 2CCD:1CSA were recommended as new soilless growth media and organic fertilizer that can improve growth and production of *Capsicum annuum L. Var. Kulai* while minimize the cultivation cost. Moreover, it also can minimize the excessive water consumption and a waste of fertilizer, and environmental pollution such as N and P leaching into groundwater, ammonia volatilization into the atmosphere, and N2O emissions via microbial denitrification.

CHAPTER 7

SUMMARY, CONCLUSION AND RECOMMENDATION FOR FUTURE RESEARCH

Chili cultivation poses challenges for farmers due to its high fertilizer requirements, leading to potential negative impacts on productivity, land quality, and environmental pollution. Excessive and frequent application of chemical fertilizers can result in decreased productivity and environmental issues. This study initially conducted laboratory analyses to assess the impact of different growth media ratios on physio-chemical properties, water and nutrient retention. Subsequently, field experiments were carried out to investigate the growth performance of *Capsicum annuum L. Var. Kulai* in a fertigation system, emphasizing the potential benefits of utilizing coconut ash and palm kernel shell biochar to reduce fertilizer consumption Laboratory results highlighted that 100% coconut ash exhibited favorable properties, including high pH, electrical conductivity, cation-exchangeable capacity, exchangeable cations K and Mg, as well as optimal bulk and particle density. It also contained elevated macronutrient and micronutrient content, enhancing nutrient retention in organic matter. The application of coconut ash showed potential to stabilize soil pH and improve soil fertility. However, field validation is necessary to confirm these findings. In the second part, 100% coconut coir dust emerged as the best growth media, positively impacting organic matter, plant growth parameters, and yield production for *Capsicum annuum L. Var. Kulai.* The application of 100% coconut coir dust improved various aspects, including plant height, stem diameter, total leaf area, chlorophyll content, flowering initiation, yield quantity and quality, root volume, and total dry weight.

This was attributed to the favorable horticultural properties of coconut coir dust, such as high moisture retention capacity and nutrient content. In the third part, growth media with 100% coconut shell ash (CSA) and a mixture of 2CCD:1CSA demonstrated superior performance, enhancing plant growth and yield while reducing fertilizer consumption by 50%. These media reduced salinity, reaching an optimal balance for plant development by improving pH, electrical conductivity, cation-exchangeable capacity, exchangeable cations, macronutrient, and micronutrient contents. The study recommends organic farming practices using agro-wastes like coconut ash and palm kernel shell biochar, which prove to be economical and eco-friendly. Further investigations are suggested, including field experiments on salinity and the implementation of slow-release fertilizers. Additionally, coconut ash and specific growth media ratios could serve as bio-inhibitors and aid in controlled nutrient release. These findings offer valuable insights for farmers and researchers aiming to enhance agricultural production while minimizing environmental impact

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APPENDICES

Appendix A

Growth Media and Ratio of Organic Matter

Growth media	Ratio(v/v)		
	CCD	**CSA**	**PKSB**
T1 (Control)	1	-	-
T2 (Control)	-	1	-
T3 (Control)	-	-	1
T4	3	1	-
T5	2	1	-
T6	1	1	-
T7	3	-	1
T8	2	-	1
T9	1	-	1

Note: Coconut coir dust (CCD), Coconut shell ash(CSA), Palm kernel shell biochar(PKSB)

Appendix B

Total Amount of Nutrient Solution

Amount and EC of nutrient solution supplied to the chilli plants used by the local grower 's practice

Day	Amount of nutrient solution (ml day^{-1})	EC of nutrient solution (dS/m)
1-7	300-500	1.2
8-14	400-600	1.3
15-21	700-800	1.4
22-28	800-1200	1.5
29-35	1200-1500	1.6
36-49	1500-1800	1.8
50-70	1800-2000	2.0
71-120	>1800	2.0-2.8

Note: Standard amount of irrigation recommended by extension agency, Department of Agriculture, Malaysia.

Appendix C

Total Amount of Nutrient Solution by Different Percentages

Day	EC of nutrient solution (dS/m)	Amount of nutrient solution (ml day^{-1})		
		100%	75%	50%
1-7	1.2	300	225	150
8-14	1.3	400	300	200
15-21	1.4	700	525	350
22-28	1.5	800	600	400
29-35	1.6	1200	900	600
36-49	1.8	1500	1125	750
50-70	2.0	1800	1350	900
71-120	2.0-2.8	>2000	>1500	>1000

Note: Amount of nutrient solution above was diluted in 300 gallons water tank.

Appendix D

Nutrient Concentrations

Nutrient concentrations (mg/L) for Cooper standard solutions used in this study

Nutrient	Concentration (mg/L)
N (Nitrogen)	200
P (Phosphorus)	60
K (Potassium)	300
Ca (Calcium)	170
Mg (Magnesium)	50
Fe (Ferum)	12
Mn (Manganese)	2
B (Boron)	1.5
Zn (Zinc)	0.1
Cu (Cooper)	0.1
Mo (Molybdenum)	0.2

Note: The solution is based on formulation by Cooper (1979)

Weight of fertilizer in 30 liter stock solution used in this study

Fertilizer / salts	Formula	Weight of salt (g) In 30 liter water
STOCK A		
Calcium nitrate	$Ca(NO_3)_2 . 4H_2O$	6668.67
Ferum EDTA	$CH_2N(CH_2.COO_2)_2FENa$	526.67
STOCK B		
Potassium dihydrogen phosphate	KH_2PO_4	1753.33
Potassium nitrate	KNO_3	3886.67
Magnesium sulphate	$MgSO_4.7H_2O$	3420
Manganese sulphate	$MnSO_4.H_2O$	40.67
Boric acid	H_3BO_3	11.33
Copper sulphate	$CuSO_4.5H_2O$	2.6
Zinc sulphate	$ZnSO_4.7H_2O$	2.93
Ammonium molibdate	$(NH_4)_6MO_7O_{24}4H_2O$	2.47

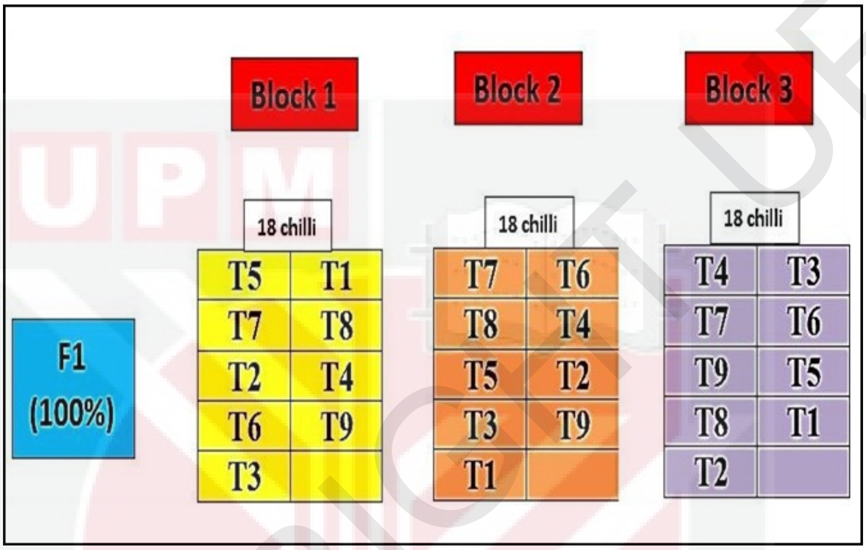
Appendix E

Field Layout Plot: Chapter 5

EFFECT OF DIFFERENT GROWTH MEDIA MIXTURES ON GROWTH PERFORMANCE OF *Capsicum annuum* UNDER FERTIGATION SYSTEM

The growth media were arranged by randomized complete block design (RCBD) arrangement with three replications and two subreplicates.

1 Fertilizer level, 9 growth media,3 replicate, and 2 subreplicate = 54 chilli



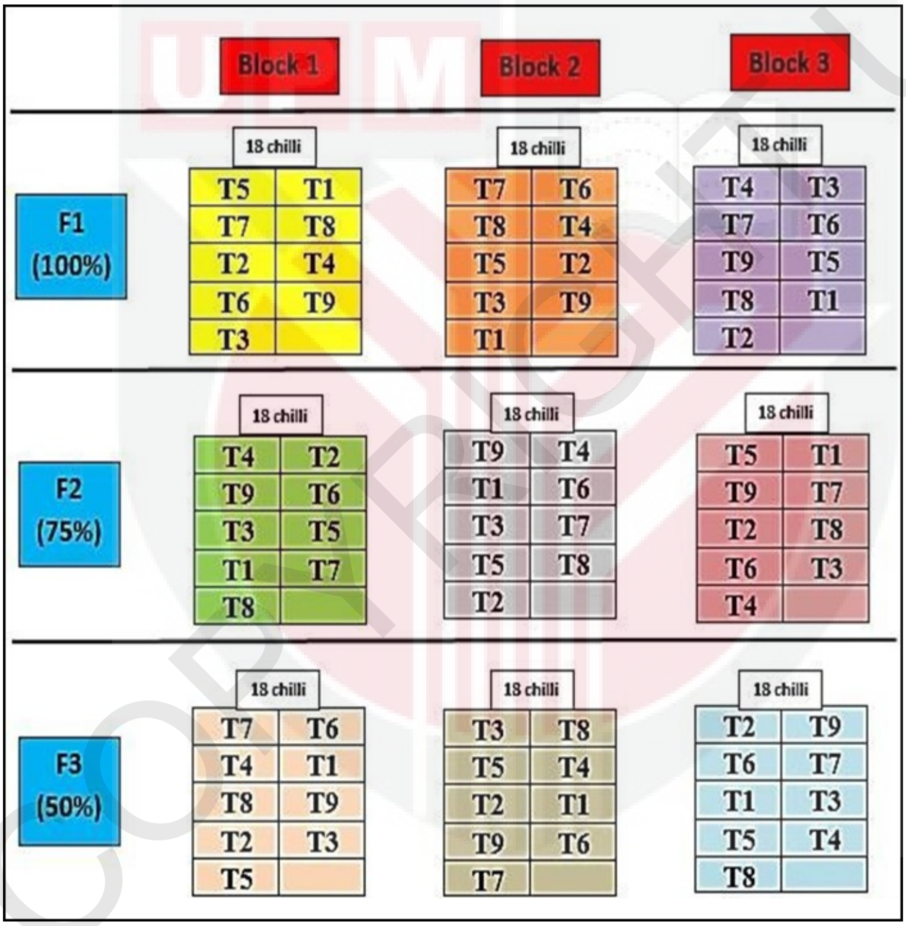
Appendix F

Field Layout Plot: Chapter 6

THE BENEFICIAL USE OF GROWTH MEDIA MIXTURES IN REDUCING FERTILIZER CONSUMPTION ON *Capsicum annuum* IN FERTIGATION SYSTEM

The growth media were arranged by Split-plot in randomized complete block design (RCBD) arrangement with three replications and two sub replicates.

(3 Fertilizer level(mainplot), 9 growth media (subplot),3 replicate, and 2 subreplicate) = 162 chilli



Appendix G

Analysis of Variance: Chapter 4

THE PHYSICO-CHEMICAL PROPERTIES IN DIFFERENT GROWTH MEDIA MIXTURE OF COCONUT COIR-DUST, COCONUT ASH, AND PALM KERNEL BIOCHAR

The growth media were arranged in a Completely Randomized Design (CRD)

a) pH (mean square)

Source of variance	DF	pH
Growth media	8	3.19***
Error	18	0.00026
CV		0.26

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

b) Electrical conductivity (mean square)

Source of variance	DF	EC (dS/m)
Growth media	8	1.68***
Error	18	0.000081
CV		0.77

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

c) Bulk density (mean square)

Source of variance	DF	Bulk Density (g/cm^3)
Growth media	8	0.22***
Error	18	0.00031
CV		4.74

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

d) Particle density (mean square)

Source of variance	DF	Particle Density (g/cm^3)
Growth media	8	0.32***
Error	18	0.00047
CV		4.17

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

e) Porosity (mean square)

Source of variance	DF	Porosity
Growth media	8	178.48***
Error	18	1.55
CV		3.98

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

f) Water retention (mean square)

Source of variance	DF	Water retention				
		Pressure Potential (kPa)				
		0	1	10	33	1500
Growth media	8	514.94***	617.32***	630.14***	763.76***	677.89***
Error	18	3.19	2.86	5.12	4.49	6.19
CV		2.22	2.20	3.92	4.17	5.48

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

g) Cation-exchange capacity (mean square)

Source of variance	DF	CEC (cmolc/kg)
Growth media	8	35.03***
Error	18	0.0034
CV		0.79

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

h) Exchangeable bases K,Ca,Mg,Na (mean square)

Source of variance	DF	Concentration (mg/L)			
		K	Ca	Mg	Na
Growth media	8	1.51***	0.031***	0.039***	0.029***
Error	18	0.000022	0.00012	0.000022	0.0000044
CV		0.38	0.40	1.20	1.66

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

i) Nutrient gaseous element and C/N ratio (mean square)

Source of variance	DF	Concentration(mg/L)			
		Nutrient gaseous element			
		C	N	S	C/N ratio
Growth media	8	306.42***	0.027***	0.0015***	9143.88***
Error	18	0.000056	0.0000074	0.0000037	0.48
CV		0.012	0.67	1.94	0.43

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

j) Macronutrient (mean square)

Source of variance	DF	Concentration(mg/L)			
		Macronutrient			
		K	Ca	Mg	P
Growth media	8	8256.36***	601.52***	212.12***	38.76***
Error	18	0.00004	0.000003	0.000007	0.0000026
CV		0.0065	0.0049	0.017	0.033

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

k) Micronutrient (mean square)

Source of variance	DF	Concentration(mg/L)			
		Micronutrient			
		Al	B	Cu	Fe
Growth media	8	5104.59***	0.031***	0.040***	1470.13***
Error	18	0.00000	0.0000020	0.0000016	0.00000
CV		0.0056	1.49	0.46	0.0060

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

l) Heavy metal and other trace element (mean square)

Source of variance	DF	Concentration(mg/L)			
		Micronutrient			
		Cd	Cr	Pb	Ti
Growth media	8	0.0000017***	0.52***	0.21***	0.14***
Error	18	0.00000081	0.0000020	0.0000014	0.0000032
CV		54.16	0.35	0.89	0.52

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

m) Nutrient retention (mean square)

Source of variance	DF	Carbon retention (%)					
		Days of Incubation					
		1	3	6	9	12	15
Growth media	8	125.80***	245.69***	361.90***	452.12***	511.48***	534.45***
Error	18	0.00024	0.00016	0.00018	0.00024	0.00018	0.00019
CV		0.053	0.033	0.030	0.031	0.024	0.024

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

n) Nitrogen content

Source of variance	DF	Nitrogen retention (%) Days of Incubation					
		1	3	6	9	12	15
Growth media	8	0.029***	0.032***	0.036***	0.042***	0.027***	0.019***
Error	18	0.0000040	0.0000038	0.0000049	0.0000033	0.0000050	0.0000044
CV		0.65	0.58	0.61	0.45	0.54	0.49

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

o) Carbon : Nitrogen content

Source of variance	DF	Carbon :Nitrogen Days of Incubation					
		1	3	6	9	12	15
Growth media	8	5664.39***	10482.24***	12687.16***	11636.88***	11501.78***	7704.81***
Error	18	0.41	1.00	1.16	0.70	1.31	0.66
CV		0.61	0.78	0.79	0.57	0.78	0.58

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

p) Sulphur retention

Source of variance	DF	Sulphur retention (%) Days of Incubation					
		1	3	6	9	12	15
Growth media	8	0.0015***	0.0014***	0.0013***	0.0022***	0.0024***	0.003068***
Error	18	0.0000042	0.0000049	0.0000039	0.0000046	0.0000047	0.0000032
CV		3.39	3.075	2.29	2.13	1.93	1.48

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

q) Potassium retention

Source of variance	DF	Potassium retention (mg/L) Days of Incubation					
		1	3	6	9	12	15
Growth media	8	269.91***	831.29***	1624.54***	3149.62***	3479.83***	3835.49***
Error	18	0.00012	0.00017	0.00018	0.0011	0.00019	0.00049
CV		0.041	0.033	0.027	0.045	0.018	0.031

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

r) Calcium retention

Source of variance	DF	Calcium retention (mg/L)					
		Days of Incubation					
		1	3	6	9	12	15
Growth media	8	2488.71***	1316.87***	349.30***	526.96***	1077.30***	1119.3***
Error	18	0.00022	0.00028	0.00018	0.00016	0.00017	0.00032
CV		0.025	0.033	0.028	0.025	0.024	0.035

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

s) Magnesium retention

Source of variance	DF	Magnesium retention (mg/L)					
		Days of Incubation					
		1	3	6	9	12	15
Growth media	8	28.47***	14.65***	14.16***	27.27***	37.40***	85.58***
Error	18	0.00015	0.00050	0.00013	0.00012	0.00037	0.00024
CV		0.11	0.17	0.079	0.069	0.11	0.076

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

t) Aluminium retention

Source of variance	DF	Aluminium retention (mg/L)					
		Days of Incubation					
		1	3	6	9	12	15
Growth media	8	2043.33***	2865.88***	2300.29***	2627.45***	4015.68***	2979.98***
Error	18	0.00006	0.00045	0.00014	0.00018	0.00008	0.00023
CV		0.035	0.085	0.046	0.049	0.028	0.056

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

u) Ferum retention

Source of variance	DF	Ferum retention (mg/L)					
		Days of Incubation					
		1	3	6	9	12	15
Growth media	8	377.56***	526.44***	603.05***	923.82***	2437.42***	6892.26***
Error	18	0.00026	0.00017	0.00027	0.00016	0.00031	0.00029
CV		0.069	0.045	0.051	0.033	0.032	0.024

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

v) Zinc retention

Source of variance	DF	Zinc retention (mg/L)					
		Days of Incubation					
		1	3	6	9	12	15
Growth media	8	0.24***	0.14***	0.14***	0.15***	0.15***	0.21***
Error	18	0.0000049	0.0000037	0.0000014	0.0000048	0.0000058	0.0000023
CV		0.68	0.64	0.37	0.67	0.78	0.38

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

w) Sodium retention

Source of variance	DF	Sodium retention (mg/L)					
		Days of Incubation					
		1	3	6	9	12	15
Growth media	8	9.35***	10.87***	13.74***	20.07***	48.78***	70.97***
Error	18	0.0000024	0.0000023	0.000046	0.000024	0.000060	0.00012
CV		0.031	0.026	0.098	0.063	0.084	0.10

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns)

x) Manganese retention

Source of variance	DF	Sodium retention (mg/L)					
		Days of Incubation					
		1	3	6	9	12	15
Growth media	8	0.84***	0.35***	0.30***	0.43***	0.48***	0.86***
Error	18	0.0000026	0.0000019	0.0000019	0.0000025	0.0000014	0.0000029
CV		0.23	0.23	0.23	0.25	0.17	0.18

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

Appendix H

Analysis of Variance: Chapter 5

EFFECT OF DIFFERENT GROWTH MEDIA MIXTURES ON GROWTH PERFORMANCE OF *Capsicum annuum* UNDER FERTIGATION SYSTEM

The growth media combinations of a 2 factorial experiment were arranged in a Randomized Complete Block Design (RCBD) with three replications.

a) Dependent variable: pH (mean square)

Source of variance	DF	pH
Growth media,gm	8	2.10***
Fertilizer,fert	1	2.39***
gm*fert	8	1.39***
Block	2	0.00094ns
Error	34	0.00043
CV		0.35

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

b) Dependent variable: Electrical conductivity (mean square)

Source of variance	DF	EC (dS/m)
Growth media,gm	8	2.63***
Fertilizer,fert	1	1.57***
gm*fert	8	0.33***
Block	2	0.00059ns
Error	34	0.00035
CV		1.39

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

c) Dependent variable: Exchangeable bases K, Ca, Mg and Na (mean square)

Source of variance	DF	Concentration(mg/L)			
		Exchangeable bases			
		K	Ca	Mg	Na
Growth media,gm	8	1.73***	4.97***	0.18***	0.14***
Fertilizer,fert	1	2.83***	905.77***	5.34***	0.014***
gm*fert	8	2.34***	4.90***	0.14***	0.028***
Block	2	0.0000017ns	0.0038ns	0.000036ns	0.000010ns
Error	34	0.000010	0.0016	0.000029	0.0000040
CV		0.32	0.59	0.77	1.40

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

d) Dependent variable: Nutrient gaseous element (mean square)

Source of variance	DF	Concentration (%)			
		Nutrient gaseous element			
		K	Ca	Mg	Na
Growth media,gm	8	342.03***	0.047***	10342.02***	0.0019***
Fertilizer,fert	1	133.01***	0.12***	22097.63***	0.0146***
gm*fert	8	66.49***	0.0031***	1586.79***	0.00082***
Block	2	0.00037ns	0.00000013ns	0.06ns	0.00000072ns
Error	16	0.00071	0.0000031	0.44	0.0000051
CV		0.044	0.39	0.47	1.95

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

e) Dependent variable: Macronutrient (mean square)

Source of variance	DF	Concentration(mg/L)			
		Macronutrient			
		K	Ca	Mg	P
Growth media,gm	8	19108.59***	4835.45***	191.19***	73.15***
Fertilizer,fert	1	848.07***	21637.22***	220.65***	51.55***
gm*fert	8	1944.96***	4546.66***	92.86***	4.77***
Block	2	0.0001ns	0.0025ns	0.00017ns	0.0000019ns

f) Dependent variable: Micronutrient (mean square)

Source of variance	DF	Concentration(mg/L)				
		Micronutrient				
		Al	Mn	Na	Fe	Zn
Growth media,gm	8	25316.12***	3.79***	981.42***	4821.49***	14.63***
Fertilizer,fert	1	17067.45***	9.51***	196.14***	9105.19***	4.87***
gm*fert	8	8797.78***	1.98***	42.53***	1436.26***	4.56***
Block	2	0.0024ns	0.000011ns	0.00048ns	0.0069ns	0.00044ns
Error	34	0.0014	0.0000067	0.00046	0.0023	0.00026
CV		0.066	0.21	0.090	0.10	1.58

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

Appendix I

Analysis of Variance: Chapter 5

EFFECT OF DIFFERENT GROWTH MEDIA MIXTURES ON GROWTH PERFORMANCE OF *Capsicum annuum* UNDER FERTIGATION SYSTEM

The growth media were arranged in a Randomized Complete Block Design (RCBD)

a) Plant height (mean square)

Source of variance	DF	Plant height (cm) Week after transplant (WAT)			
		2	4	6	8
Growth media	8	6.59ns	47.01***	118.07***	149.33***
Block	2	6.26ns	20.26ns	49.93ns	13.00ns
Error	16	3.26	7.26	17.84	9.21
CV		9.43	11.00	13.66	9.10

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

Source of variance	DF	Plant height (cm) Week after transplant (WAT)			
		10	12	14	16
Growth media	8	186.50***	200.82***	246.17***	288.33***
Block	2	2.11ns	13.37ns	8.11ns	18.78ns
Error	16	4.40	4.29	2.53	6.15
CV		5.71	5.44	3.91	5.74

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

b) Stem diameter (mean square)

Source of variance	DF	Stem diameter (mm) Week after transplant (WAT)			
		2	4	6	8
Growth media	8	0.031ns	1.23***	3.40**	5.27***
Block	2	0.14ns	0.30ns	1.68ns	2.13ns
Error	16	0.06	0.12	0.57	0.71
CV		7.87	8.60	14.48	14.07

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

Source of variance	DF	Stem diameter (mm)			
		10	12	14	16
Growth media	8	5.94***	3.56***	3.28***	5.27***
Block	2	1.82ns	1.58ns	1.05ns	0.72ns
Error	16	0.53	0.46	0.31	0.22
CV		10.67	8.66	5.95	4.57

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

c) Days of flowering (mean square)

Source of variance	DF	Days of flowering		
		Initial	50%	Fruit set
Growth media	8	8.32***	7.37***	7.75ns
Block	2	0.037ns	0.70ns	1.33ns
Error	16	0.37	0.33	3.13
CV		1.37	1.16	3.19

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

d) Number and weight of yield (mean square)

Source of Variance	DF	Number of yields	Weight of yield (g)
Growth media	8	694.50***	218655.00***
Block	2	3.44ns	78.11ns
Error	16	9.44	162.861
CV		10.98	2.61

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

e) Total leave area (mean square)

Source of Variance	DF	Total leave area (cm^3)
Growth media	8	2206130.33***
Block	2	952.94ns
Error	16	1175.66
CV		1.56

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

f) Root length, root diameter, root surface area and root volume (mean square)

Source of variance	DF	Root Size and Distribution			
		Length (cm)	Diameter (mm)	SA (cm^2)	Volume (cm^3)
Growth media	8	10834.00***	0.28***	6399.65***	11.18***
Block	2	7.78ns	0.012ns	0.29ns	0.060ns
Error	16	11.10	0.016	7.61	0.067
CV		0.99	8.81	1.53	4.81

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

g) Leaf dry weight, root dry weight, stem dry weight and root to shoot ratio (mean square)

Source of variance	DF	Total Dry Weight			Root : Shoot Ratio
		Plant Partition			
		Leaf	Stem	Root	
Growth media	8	368.74***	587.96***	101.13***	0.0029***
Block	2	0.61ns	3.55ns	0.53ns	0.00036ns
Error	16	3.20	2.02	0.86	0.00027
CV		5.34	4.76	6.19	6.94

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

h) Fruit Nutrient Content (mean square)

Source of Variance	DF	Concentration (%)			
		Nutrient gaseous element			
		C	N	C/N ratio	S
Growth media	8	62.24***	0.017***	5735.60***	0.0015***
Block	2	0.00063ns	0.000012ns	0.65ns	0.00000070ns
Error	16	0.0011	0.0000085	1.67	0.0000071
CV		0.11	1.07	1.11	6.31

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

Source of variance	DF	Concentration(mg/L)			
		Macronutrient			
		K	Ca	Mg	P
Growth Media	8	180.47***	42.39***	35.65***	38.21***
Block	2	0.028ns	0.00081ns	0.00035ns	0.00031ns
Error	16	0.0086	0.00079	0.00011	0.00084
CV		0.42	0.13	0.065	0.21

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

Source of variance	DF	Concentration(mg/L)				
		Micronutrient				
		Al	Mn	Na	Fe	Zn
Growth media	8	5.32***	0.13***	6.75***	29.45***	0.12***
Block	2	0.000022ns	0.000019ns	0.00045ns	0.0000058ns	0.000003ns
Error	16	0.000017	0.000017	0.00028	0.0000063	0.0000034
CV		0.30	2.46	0.18	0.070843	0.67

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

i) Chlorophyll content (mean square)

Source of variance	DF	Chlorophyll content
Growth media	8	173.96***
Block	2	0.33ns
Error	16	1.13
CV		2.11

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns)

Appendix J

Analysis of Variance: Chapter 6

THE BENEFICIAL USE OF GROWTH MEDIA MIXTURES IN REDUCING FERTILIZER CONSUMPTION ON *Capsicum annuum* IN FERTIGATION SYSTEM

The growth media combinations of a factorial experiment were arranged in a Split Plot Design.

a) pH (mean square)

Source of variance	DF	pH
Growth media,gm	8	1.06***
gm*block	16	0.00084ns
Fertilizer,fert	2	0.0021*
gm*fert	16	0.26***
Block	2	0.0028ns
Error	36	0.00062
CV		0.44

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

b) Electrical conductivity (mean square)

Source of variance	DF	EC (dS/m)
Growth media,gm	8	1.39***
gm*block	16	0.00042ns
Fertilizer,fert	2	4.89***
gm*fert	16	0.19***
Block	2	0.0014ns
Error	36	0.00028
CV		1.60

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns)

c) Exchangeable bases K,Ca,Mg, and Na (mean square)

Source of Variance	DF	Concentration(mg/L)			
		Exchangeable bases			
		K	Ca	Mg	Na
Growth media,gm	8	1.32***	53.41***	1.80***	0.18***
gm*block	16	0.0057ns	0.0031ns	0.00028ns	0.0000043ns
Fertilizer,fert	2	0.064***	50.29***	1.45***	0.019***
gm*fert	16	1.48***	12.87***	0.67***	0.067***
Block	2	0.0051ns	0.0084ns	0.00097ns	0.000015ns
Error	36	0.0054	0.0036	0.00032	0.0000047
CV		9.74	0.50	1.40	1.18

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

d) Nutrient gaseous element (mean square)

Source of Variance	DF	Concentration(%)			
		Nutrient gaseous element			
		C	N	C/N ratio	S
Growth media,gm	8	482.98***	0.059***	12956.15***	0.0026***
gm*block	16	0.0013ns	0.0000066ns	1.43ns	0.0000091ns
Fertilizer,fert	2	38.13***	0.099***	13618.94***	0.0031***
gm*fert	16	35.68***	0.0043***	681.62***	0.0011***
Block	2	0.000004ns	0.0000023ns	0.16ns	0.000011ns
Error		0.0011	0.0000088	1.65	0.0000084
CV		0.055	0.68	0.89	2.41

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

e) Micronutrient (mean square)

Source of variance	DF	Concentration(mg/L)				
		Micronutrient				
		Al	Mn	Na	Fe	Zn
Growth media,gm	8	44982.33***	2.60***	571.41***	5182.59***	6.31***
gm*block	16	0.0027**	0.000011ns	0.0011ns	0.0038*	0.00020ns
Fertilizer,fert	2	12209.60***	1.64***	1138.27***	380.06***	0.46***
gm*fert	16	6207.21***	3.05***	55.22***	1681.29***	1.12***
Block	2	0.0078ns	0.000034ns	0.0037ns	0.013ns	0.00070ns
Error	36	0.0010	0.0000083	0.00069	0.0017	0.00019
CV		0.050	0.19	0.14	0.087	1.72

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

f) Plant height (mean square)

Source of variance	DF	Plant height (cm) Week after transplant (WAT) 2	4	6	8
Growth media,gm	8	24.53*	142.50***	268.78***	384.99***
gm*block	16	6.45ns	10.72ns	16.22ns	11.73ns
Fertilizer,fert	2	0.26ns	5.33ns	106.04**	36.90*
gm*fert	16	6.26ns	28.93***	49.48**	76.19***
Block	2	3.11ns	8.04ns	13.81ns	1.64ns
Error	36	5.15	8.40	15.36	10.59
CV		11.78	12.04	13.67	10.13

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns)

g) Stem diameter (mean square)

Source of variance	DF	Stem diameter (mm) Week after transplant (WAT) 2	4	6	8
Growth media,gm	8	0.029ns	1.79***	5.58***	6.60***
gm*block	16	0.05ns	0.21ns	0.40ns	0.35ns
Fertilizer,fert	2	0.16ns	0.64ns	4.29***	3.82**
gm*fert	16	0.076ns	1.22***	1.08*	1.89***
Block	2	0.029ns	0.23ns	0.85ns	0.60ns
Error	36	0.08	0.23	0.36	0.47
CV		9.56	12.20	12.46	12.22

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

Source of variance	DF	Stem diameter (mm) Week after transplant (WAT) 10	12	14	16
Growth media,gm	8	5.86***	6.44***	8.89***	10.27***
gm*block	16	0.33ns	0.31ns	0.21ns	0.15ns
Fertilizer,fert	2	8.30***	13.26***	31.73***	42.49***
gm*fert	16	2.51***	1.98***	1.86***	2.49***
Block	2	0.55ns	0.38ns	0.31ns	0.17ns
Error	36	0.37	0.29	0.23	0.20
CV		9.73	7.62	5.98	5.06

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

h) Number and weight of yield (mean square)

Source of Variance	DF	Number of yields	Weight of yield (g)
Growth media,gm	8	1381.53***	470027.19***
gm*block	16	5.89ns	86.90ns
Fertilizer,fert	2	616.31***	177375.44***
gm*fert	16	391.64***	119538.57***
Block	2	2.98ns	56.78ns
Error	36	8.51	141.28
CV		9.40	2.18

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

i) Total leave area (mean square)

Source ofvariance	DF	Total leave area (cm^3)
Growth media,gm	8	4600364.20***
gm*block	16	899.54ns
Fertilizer,fert	2	212633.81***
gm*fert	16	1358860.46***
Block	2	3099.14ns
Error	36	736.02
CV		1.29

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

j) Leaf dry weight, root dry weight, stem dry weight and root to shoot ratio (mean square)

Source of variance	DF	Total Dry Weight			Root : Shoot Ratio
		Plant Partition			
		Leaf	Stem	Root	
Growth media,gm	8	709.15***	859.69***	281.36***	0.013***
gm*block	16	1.84ns	1.15ns	0.46ns	0.00013ns
Fertilizer,fert	2	10.49*	39.93***	16.82***	0.0012*
gm*fert	16	272.60***	320.33***	67.36***	0.0061***
Block	2	1.36ns	3.94ns	1.57ns	0.00023ns
Error	36	2.24	0.71	0.73	0.00033
CV		4.56	2.91	5.62	7.48

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

k) Fruit Nutrient Content (mean square)

Source of Variance	DF	Concentration(%)			
		Nutrient gaseous element			
		C	N	C/N ratio	S
Growth media,gm	8	271.41***	0.021***	12655.72***	0.0014***
gm*block	16	0.00056ns	0.0000078ns	1.87ns	0.0000044ns
Fertilizer,fert	2	55.22***	0.0057***	89.85***	0.00048***
gm*fert	16	59.78***	0.015***	1119.17***	0.00086***
Block	2	0.00041ns	0.000015ns	2.61ns	0.00000023ns
Error		0.0010	0.0000071	1.68	0.0000079
CV		0.10	0.93	1.13	5.99

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

Source of Variance	DF	Concentration(mg/L)			
		Macronutrient			
		K	Ca	Mg	P
Growth media,gm	8	385.15***	1481.42***	788.07***	114.72***
gm*block	16	0.012ns	0.00056ns	0.00029ns	0.00055ns
Fertilizer,fert	2	4.43***	19687.79***	10610.53***	33.93***
gm*fert	16	54.04***	910.43***	264.76***	19.44***
Block	2	0.036ns	0.0019ns	0.00088ns	0.00032ns
Error	36	0.0078	0.00058	0.00016	0.00061
CV		0.41	0.059	0.042	0.17

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

Source of variance	DF	Concentration(mg/L)				
		Macronutrient				
		Al	Mn	Na	Fe	Zn
Growth media,gm	8	4.59***	0.20***	6.22***	15.58***	0.13***
gm*block	16	0.0000074ns	0.0000096ns	0.000087ns	0.0000085ns	0.0000072ns
Fertilizer,fert	2	21.11***	0.57***	151.57***	16.93***	1.67***
gm*fert	16	7.06***	0.079***	4.70***	22.58***	0.22***
Block	2	0.000020ns	0.000027ns	0.00023ns	0.000029ns	0.000025ns
Error	36	0.0000085	0.000011	0.00010	0.0000096	0.0000057
CV		0.15	1.20	0.15	0.089	0.58

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

l) Chlorophyll content (mean square)

Source of Variance	DF	Chlorophyll content
Growth media,gm	8	382.13***
gm*block	16	0.97ns
Fertilizer,fert	2	68.51***
gm*fert	16	179.42***
Block	2	0.36ns
Error	36	0.79
CV		1.73

Note: * = p≤0.05; ** = p≤0.01;***= p≤0.001; non-significant (ns).

BIODATA OF STUDENT

Natrah Azira binti Amran was born in 11 October 1993 in Kuala Lipis, Pahang. She began her primary school in Sekolah Kebangsaan Wan Ibrahim in 2000. Later, she extended her secondary education in Sekolah Menengah Kebangsaan Setia Wangsa in 2006 and completed her SPM in 2010. She furthered her study in Bachelor Degree in Agriculture Biotechnology. She obtained her Bachelor Degree in 2017 and enrolled to her Master Degree study majors in Soil Science at Department of Land Management, Faculty of Agriculture, UPM. During her study period, she has participated as poster presenter in Soil Science Conference of Malaysia (SOILS 2019) on 16 to 18 April 2019. She has published the proceeding paper entitle “The pH and Electrical Conductivity of Coconut Ash, Zeolite, and Palm Oil Mill Effluent (POME)”. She was ambitious to be a lecturer and agriculture officer. The author love nature and agriculture. She was hoping that agriculture in Malaysia could be an outstanding field in the world occupied with a new technology and innovation.

PUBLICATION

Amran, N. A., Kasim, S., Shuib, E. M., & Yusoff, M. M. Improvement of Growth Media Quality Using Coconut Coir Dust, Coconut Ash, and Palm Kernel Shell Biochar. AgriHealth: Journal of Agri-food, Nutrition and Public Health, 5(2), 150-173.