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WEST AFRICAN CENTER FOR WATER, IRRIGATION AND SUSTAINABLE AGRICULTURE

IRRIGATION REGIMES AND GROWTH MEDIA EFFECTS ON GROWTH AND YIELD OF GREENHOUSE CUCUMBER (*Cucumis sativus* L.)

KAREEM MARIAM OLAMIDE

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BY

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March, 2023

DECLARATION

Student

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this University or elsewhere, except for references which have been properly cited.

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We hereby declare that the preparation and presentation was supervised in accordance with the guidelines on supervision of thesis laid down by the University for Development Studies, Ghana.

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ABSTRACT

Challenges facing vegetable farmers in Ghana include the inability to determine the particular amount of water required by the crops during different growth stages and adoption of the necessary irrigation practices to maximise profit. Cucumber productivity can be increased by practicing protected cultivation in the form of greenhouse, as it provides a less restrictive environment for growth and development in contrast to open – field cultivation. Although, greenhouse cucumber production increases productivity, the risk of soil borne diseases has negative effect on the crop. This research was carried out in a greenhouse located at Council for Scientific and Industrial Research (CSIR) - Savanna Agricultural Research Institute (SARI), Nyankpala, Northern Region of Ghana from June, 2022 to September, 2022. The study compared the yield obtainable with greenhouse cucumber grown on soil with cocopeat and soil - biochar mixture and the resultant effect on growth and yield under irrigation regimes. The experiment was a 3 x 3 factorial study laid out in Randomized Complete Block Design (RCBD) with three replications. The treatments consisted of irrigation regimes (100 % ET_c., 75 % ET_c, 50 % ET_c) and growth media including (Soil (So), Soil plus Charred rice husk (So + CRH) and Cocopeat (CP)). From the CROPWAT model, the cucumber with highest water requirement for all media was at 100 % ET_c giving a value of 237.4 mm/ dec for both So and So + CRH and 237.2 mm/dec for CP; that of lowest water requirement was at 50 % ET_c giving a value of 118.8 mm/dec for both So and So + CRH and 118.6 mm/dec for CP. Data was collected on media physico-chemical properties, growth and yield parameters. Determination of the cost benefit of the media also took place. The result of Analysis of Variance (ANOVA) showed CP and So + CRH at 100 % ET_c supported optimum growth of greenhouse cucumber. Cucumber growth parameters including: plant height, leaf number per plant, stem girth and flower count were maximised on CP at 100 % ET_c. Highest leaf area index was obtained from plants grown on So + CRH at 100 % ET_c; chlorophyll content was highest for cucumber plants grown on So at 50 % ET_c, while the highest flower abortion occurred on plants grown on So + CRH at 75 % ET_c. Plants irrigated at 100 % ET_c gave the highest yield of 116.3 t/ha while those irrigated at 50 % ET_c gave the lowest yield of 37.8 t/ha. Plant height correlated highly and positively with stem girth and flower count at r = 0.65 and 0.62 respectively; Leaf area index correlated highly and positively with the flower count at r = 0.63 and total fruit count correlated highly and positively with the fruit yield at r = 0.85. Most of the growth parameters were optimal at 100 % ET_c and yield obtained from plants irrigated at 75 % ET_c was similar to that obtained at 100 % ET_c; it is therefore recommended for greenhouse cucumber farmers in northern Ghana to irrigate at 75 % ET_c thereby saving water and optimizing yield. Use of So proved to be more profitable compared to CP and So + CRH. This could be due to the high cost of production of CP and high flower abortion associated with So + CRH grown plants, which reduced the yield. More work could be done on combination of CP and CRH for greenhouse cucumber production.

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DEDICATION

I dedicate this research work to Almighty Allah, my loving family and myself.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
AWC	Available water content
%	Percentage
BD	Bulk density
BCR	Benefit Cost Ratio
^{o}C	Degree Celcius
CBA	Cost Benefit Analysis
cm:	Centimeter
CP	Cocopeat
CRH	Charred rice husk
CSIR	Council for Scientific and Industrial Research

CV (%)	Coefficient of variation
DU	Distribution uniformity
DI	Deficit irrigation
DAP	Days after planting
DAT	Days after Transplanting
Ea	Field application efficiency
EC	Electrical conductivity
et al	and others
FAO	Food and agricultural organization
FAOSTAT	FAO Statistics
FC	Field capacity
IRg	Gross irrigation requirement
IRn	Net irrigation requirement
K	Potassium
Kc	Crop factor
Kg	Kilogram
LSD	Least Significant Difference
l/hr	Liter per hour

MAD	Maximum allowable depletion
Max	Maximum
MC	Moisture content
Mg	Magnessium
Min	Minimum
ml	Millilitre
mm	Millimetre
MoFA	Ministry of Food and Agriculture
N	Nitrogen
N.P.K	Nitrogen, Phosphorus and Potassium
P	Phosphorus
Pd	Ground cover (%)
Pe	Effective rainfall
P^H	Power of hydrogen
PWP	Permanent wilting point
RAW	Readily available water
SARI	Savanna Agricultural Research Institute
SEM	Standard Error of Means

So	Soil
So + CRH	Soil plus Charred Rice Husk
TAW	Total available water
WAT	Weeks after transplanting
WP	Water productivity

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Globally, as time changes, agriculture is becoming more important as the need for intensifying production is on the increase to achieve zero hunger as specified by the second Sustainable Development Goal (SDG 2). Kyei-Baffour & Ofori (2005) pointed out that economic growth and poverty reduction cannot be achieved in Ghana except with recognizable improvement in the agricultural sector.

Water availability is usually the most important factor limiting agricultural production in Northern Ghana. Northern Ghana is characterized by mono – modal highly variable rainfall such that the region experiences only about six months of rain, but interspersed with frequent and unpredictable drought (Mawunya *et al.*, 2012). Therefore, in such semi-arid environments, farmers rely on other sources of water other than rainfall to irrigate their crops to obtain more sustainable crop production. Irrigation has been suggested to play a vital role in food scarcity control and poverty alleviation. It serves as a sure way of improving agricultural productivity (Porter *et al.*, 2014).

Wang *et al.* (2021) stated that irrigation is an important option for increasing crop production and reducing drought impacts.

Presently, farmers in Northern Ghana have adopted different irrigation systems for enhancing production of vegetables, some of these methods include: Surface irrigation method which entails flow of water by gravity over the soil, this water is usually supplied through canals, ditches or pipes to the field. However, in some locations, water may need to be pumped from the source to a field at a higher elevation. It is cheaper and easier to construct and maintain, it however requires the land to have a gentle slope, making it labour intensive and often resulting to flooding of low areas. The efficiency of these systems varies greatly depending on soil type, field uniformity, crop type and management. This irrigation system is seen as being less efficient as compared to sprinkler irrigation and micro - irrigation because earth channel or canal, not a pipe conveys water within the field. Types of surface irrigation systems include: basin, furrow and border irrigation.

Sprinkler irrigation is however a method of irrigation where water is sprayed from the air and allowed to fall on the soil surface, in a similar way as rainfall, through nozzles under high pressure. As compared to the surface irrigation method, sprinkler systems can be used on unlevelled land, there is regulation and maximization of the amount of water applied, it involves low labour requirement, trees are controlled against freezing (Parsons *et al.*, 1991), it is however costly to obtain and mostly affected by wind velocity which prevents the applied water from getting to where intended. It also requires high power to produce the required high pressure needed to pump water into pipes.

Drip irrigation on the other hand, is the most efficient water and nutrient delivery system for growing crops as both water and nutrients are applied directly to the plant's root zone, in the right amount and at the right time such that each plant gets its exact requirement as at when needed, it can also be used on sloping land, it is however expensive to install. Drip irrigation has been recommended to be an efficient water-saving application technique. It provides small and consistent water applications directly to the vicinity of the plant root zone, thus, attracting a lot of interest due to the low water requirement and expected increase in production (Darwish *et al.*, 2006; Janat, 2007). According to Awe *et al.* (2020), drip irrigation technology has been advocated to ensure the optimal use of water and nutrients for agriculture and improving irrigation efficiency.

Greenhouse cultivation, recently, has been strongly advocated as an important factor in employment generation due to its impact in producing off season agricultural products, improving use of water and soil resources and making maximum utilization of facilities in the rural communities and urban areas that suffer problem of water scarcity (Hassanpour *et al.*, 2013). Sutherland (1988) confirmed that, as compared to cucumber plants grown in open field conditions, greenhouse cucumber plants are known for their high nutrient and water uptake, rapid vegetative and reproductive growth rates, and large root masses. Greenhouses are a form of protected cultivation, and they are a good option for vegetable production, especially in areas like Ghana where problems of produce seasonality and perishability are mostly encountered, as they provide coping mechanism for climate change impacts.

Soilless culture is a method of growing plants without the use of soil (Savvas *et al.*, 2013), it involves provision of alternate media for anchorage to the plants and serving as a storage for water and nutrients. Hussaine *et al.*, (2014) stated that soilless culture involves the cultivation of plants by imitating soil – base gardening and utilizing different kinds of growing media. Examples of these media include, organic substances, inorganic substances and synthetic substrates. Soilless culture is one of the fastest growing sectors in agriculture that helps in speeding up food production. When an artificial substrate is used as the growth media, it allows effective and efficient use of water and fertilizers and minimises the use of chemicals for pest and disease management. Plants grown using the soilless culture have been discovered to have high nutrient content and superior quality as compared to the ones grown on soil.

Rice husk is the natural sheath which forms the cover of rice grains during their growth, it is a by – product of the rice milling industry and according to Esa *et al.* (2013), it accounts for 20% of the whole rice grains. According to Awang *et al.* (2009), due to its granular structure, high mechanical strength, chemical stability and insolubility in water coupled with the fact that is easily accessible at little or no cost, rice husk has been selected as a starter material. Another advantage of rice husk is that, with its application, the need for regeneration is not necessary as it doesn't cost much in the aspect of production. Rice husk is made up of 37% carbon and 20% ash; this ash is primarily made up 94% SiO_2. It was therefore concluded, from the work of Aly (1992) &Tran *et al.* (1999), that due to its high silica content, rice husk is also important as a nutrient absorber. Charred rice husk is the burnt rice husk. It is rich in silica and potassium. It serves as a nutrient source to the plant, it also absorbs odor and keeps the root system clean.

Coconut coir is a fibrous material which is found on the inside of coconut shells, it is also referred to as cocopeat, ultra peat and coco – tex. Until recently, it has been considered as a waste material; but now, however, it often serves to aerate the soil or to even act as a medium on its own. It has common characteristics with vermiculite and perlite which has water and air retention respectively. It has a neutral p^H level, it is completely organic in nature, and made from shredded coconut husks. Before the discovery of cocopeat, peat moss was often used, but due to the acidic nature of peat moss, it is important to neutralize it with products like limestone. This, however, is not necessary in the case of cocopeat due to its associated neutral p^H. It is seen as an efficient growing media with suitable EC, p^H and other chemical properties.

Ghehsareh *et al.* (2011) indicated that the water holding capacity (WHC) of cocopeat is estimated to be 90.5%, whereas for other substrates like perlite and date – palm, the water holding capacities are 96.7% and 78.3% respectively. Its high WHC and air – filled porosities thereby aids seed germination rate and produces stronger and fibrous seedlings (Fornes *et al.*, 2003). Cocopeat aids aeration thereby increasing the rate at which water drains through. At the same time, it is a good absorbent and retains moisture for plant utilization. It is highly sustainable due to the fact that it is a natural by – product of coconut production and therefore easily replaceable.

Cucumber (*Cucumis sativus* L.) is an important creeping vegetable and one of the most popular members of the Cucurbitaceae family with a high consumer demand globally (Eifediyi & Remison, 2010). It is a monoecious annual crop that has been cultivated by man for over 3,000 years (Okonmah, 2011). Due to its high nutrient requirements, it does not perform well on nutrient-deficient soils, leading to low yields and bitter fruits (Grubben & Denton, 2004). Enujeke (2013) mentioned that cucumber is loved by men and eaten in salads or sliced into stew in tropical regions. In terms of economic importance, it is ranked fourth after tomatoes, cabbage, and onion in Asia and second after tomato in Western Europe (Eifediyi & Remison, 2010), though its place has not been established in tropical Africa because of limited use. Cucumber serves as a good source of vitamins A, C, K, and B6, potassium, pantothenic acid, magnesium, phosphorus, copper, and manganese (Vimala *et al.*, 1999). Its juice is often recommended as a source of silicon to improve the health and complexion of the skin (Duke, 1997). Okonmah (2011) confirmed that cucumber helps to reduce skin irritation due to the presence of ascorbic acid and caffeic acid.

1.2 Problem Statement and Justification

Agricultural production in Ghana, particularly in the Northern part, is being threatened due to increased water scarcity and increased competition for the available water resources, leading to an insufficient water supply for agricultural production. Due to this limitation in the availability of water, it becomes imperative to know how to irrigate timely with the least amount of water, which will optimize yield, water efficiency, and profit (Payero *et al.*, 2009). Several plant disorders and diseases might be encountered when irrigation is not properly managed during production.

Itier (1996) stated that production under limited water application usually affects crop yield adversely by reducing yield. During these periods of limited water supply, farmers tend to improvise by increasing irrigation interval, leading to a problem in balancing the supply and demand of water. One challenge facing vegetable farmers in Ghana is their inability to determine the particular amount of water required by the crop and adopt the necessary irrigation practices during the growing season to ensure profit maximization. This usually leads to over-irrigation or under irrigation resulting in water stress, both of which affect the growth, yield, and quality of the crops (Owusu-Sekyere & Dadzie, 2009). As compared to grain crops, Cucumber, one of the most popular vegetables cultivated in the world, requires more water for optimum performance (Li and Wang, 2000).

Mao *et al.* (2003) observed that, fruit yields of cucumber that were highly affected by irrigation regimes were those that had water deficiencies during fruiting stages. With drip irrigation, however, there would be minimal soil moisture variation in the root zone from the beginning to the end of the growing season, this is due to the small area of wetted soil (Kamal *et al.*, 2009).

Agricultural productivity is being threatened by changing weather patterns which result in climate change, increased rainfall variability and temperature fluctuations (Malhotra and Srivasta, 2014;Garba *et al.*,2020). One of the adaptive strategies that can help cope with these changes is greenhouse cultivation which helps in regulating the plant's macro and micro environment, improving yield and quality of the produce and optimizing plant growth and development (Gruda, 2014).

Smith and Sunil (2016) also stated that, to increase productivity of cucumber, protected cultivation in the form of greenhouse is the best option as it provides a less restrictive environment for plant growth and development in contrast to those grown in the open field condition. In many tropical regions of the world, greenhouses are used for vegetable production in order to provide a better environment that enhances good growth and development, resulting in high yield and prolonging the production cycle (Alsadon *et al.,* 2016; Degannes *et al.,* 2014; Z. Khan *et al.,* 2012). Cultivation of cucumber under greenhouse condition gives increased productivity and higher fruit quality, resulting in better market price in addition to the all year - round production. With this, cucumber becomes one of the major lucrative vegetables cropped under greenhouse conditions (El-Wanis *et al.,* 2012; Ibeawuchi *et al.*, 2008; Kumar *et al.*, 2015).

Soil is often the most available medium for growing plants as it supplies water, nutrient, air and support which are all necessary for plant growth (Sepehri *et al.,* 2018). However, most times, it has been found that cultivating vegetables in soil under greenhouse condition gives rise to risk of soil borne diseases including woot roots, root-knot nematode and root rots amongst others that has a negative effect on cucumber production (Cohen *et al.,* 2015; Elings *et al.,* 2015; Gamliel & Van Bruggen, 2016). Some other problems encountered with growing plants on soil in the greenhouse include the low water holding capacities associated with some soils, temperature fluctuation, improper root aeration and lack of available nutrient, poor produce quality, low yield, high cost of disinfectants amongst others (De Rijck & Schrevens, 1998; Du Plooy *et al.,* 2012).

Most at times, there is difficulty in obtaining fertile arable lands, in this case, the soilless culture comes in handy. This culture does not involve the regular fumigation which is mostly done to soils and which leaves behind side effects on crops thereby causing health problems to man.

Barrett *et al.* (2016) mentioned that, soilless cultivation has been known internationally for its ability to maintain efficient plant production. These media are also relatively light weight, readily available and more uniform than mineral soils (Yuan *et al.*, 1996). Savvas *et al.*, (2013) reinstated that there are several advantages of growing plants under soilless culture in comparism to the soil – based culture. A clean working environment is ensured thereby eliminating high labour cost. It is useful also in regions where there is limited arable and fertile land for agriculture (van den Broek *et al.*, 1988).

It is a good alternative for vegetable production as it reduces soil related problems experienced in conventional crop production (Olympios, 1992). As compared to the soil – based media, the soilless media are easier to handle, they provide a better environment for plant growth and development, they influence availability of water and nutrient as well as p^H in the crop root zone (Bittsanszky *et al.*, 2016; Mastouri *et al.*, 2005). This study compared the growth and yield of cucumber grown on soil to those grown on cocopeat and soil mixed with biochar at different irrigation regimes.

1.3 Objectives of the Study

1.3.1 Main Objective

To study the effects of irrigation regimes and growth media on growth and yield of greenhouse cucumber in Tolon District of Northern Region, Ghana

1.3.2 Specific Objectives

The specific objectives of the study are to:

i. Determine the effects irrigation regimes on cucumber growth and yield

ii. Assess the physico – chemical properties of the growth media (soil, cocopeat and soil mixed with charred rice husk) and their effects on cucumber growth and yield

iii. Assess the combined effects irrigation regimes and growth media on cucumber growth and yield

iv. Determine the relative water and economic performance of treatments with cost - benefit ratio

1.4 Research Questions

i. How does irrigation regimes affect cucumber growth and yield?

ii. How does the physico-chemical properties of the growth media affect cucumber growth and yield?

iii. What effect does irrigation regimes and the different growth media have on cucumber growth and yield?

iv. What is the relative water and economic performance of the different treatments with relation to cost-benefit ratio?

1.5 Scope and Limitations of the Study

This work gave an insight on the type of action growth media performed with respect to greenhouse cucumber growth and yield when different water application were considered. Enough time could have afforded us carry out some secondary growth analysis including net assimilation rate (NAR), Leaf weight ratio (LAR) and relative growth rate (RGR) and also to repeat the work in a different season to observe notable changes in the growth and yield of the plant.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 CUCUMBER

2.1.1 Origin and Cultivar groups of cucumber

Cucumber (*Cucumis sativus*), a member of the genus Cucumis and family Cucurbitaceae is a fruit vegetable globally known for its economic importance. Other members of this family include water melon, pumpkin, squash and muskmelon. In a statement of Sebastian *et al.* (2010) cucumber is said to be native to India and to likely originate from the foothills of the Himalayan Mountain. The most important cultivars originate from Europe and America, the western part of India, China and the Himalayas. It is one of the oldest vegetables mentioned throughout history. Cucumber was cultivated about 3000 years ago in India, spreading to Western Asia, and then to Southern Europe (Lv *et al.,* 2012). Respectively, it was introduced to North China by the Silk Route and to South China from Burma and India – China border, and then it spread to East Asia (Lv *et al.*,2012). Due to its enclosed dicotyledonous seeds and the fact that it develops from a flower, cucumber is classified as a fruit (Mukherjee *et al.,* 2013). Although cucumber is monoecious (that is, male and female flowers separate on the same plant), most of the varieties developed within the past forty to fifty years have been found to be gynoecious (that is, they produce mostly female flowers), and there would therefore be need for provision of monoecious pollinator plants in the field to ease pollination (Iowa State University, 2020). Guan (2018) stated that, Parthenocarpic varieties are mostly used in greenhouses and high tunnel production owing to the fact that they do not require pollination to develop fruit. From Genome variation analysis, it was seen that cucumber core germplasms were divided into four geographic groups which include: India, Eurasia, East Asia and Xishuangbanna (Qi *et al.*, 2013).

2.1.2 Varieties of Cucumber

Based on their uses, cucumbers are classified into two major categories which includes the slicing and pickling cucumbers.

Slicing cucumbers are consumed fresh from the garden, they are uniform with thick and dark – green skin which reduces their susceptibility to damage during handling and transporting. They vary in size, ranging from about 10 to 30 cm, their skin is also relatively smooth. In the presence of spines, they are normally white. Pickling cucumbers are however much smaller, with sizes ranging from 3 to 13 inches. They are mainly grown for canning; they usually have bumps on their skin and also spines that are black in color. They can be described as being short and blocky with thin skin. Their color varies from dark green at the stem end to light green at the blossom end. A type of immature pickling cucumber referred to as Gerkins are relatively small in size with warty skin. It is cultivated in nearly all countries of temperate zones and also tropical regions throughout the world (Vora *et al.*, 2014). In 2019, the total production of cucumber was 87,805,086 tons worldwide with Asia being the largest producer accounting for 84.9% of the world's total production (FAO, 2019).

2.1.3 Botany and reproductive biology of cucumber

Cucumber is an annual climbing herbaceous plant which is day neutral. It is monoecious, with rough stem which is vine with varying degree of apical dominance. The stem has its cross section being rhombus in shape and the epidermis has burrs. Also, the axillae on the stem is known for branching, with the number of branches varying significantly among varieties. Its leaves are triangular – ovate, with mostly acute curves. The flower can be axillary, unisexual and occasionally hermaphrodite. The color of young cucumber fruit changes, varying from white to pale green, while the mature fruit is yellow or brown when ripened. The calyx (green with bristles) and corolla (yellow) of staminate, pistillate and hermaphrodite flowers are five lobed. The staminate flowers are usually in clusters with short and slender pedicels and they have three stamens, two of which has two locules each with the third being unilocular. The filaments are known to be free, but the stamens are united by their anthers. The pistillate flowers are epigynous, solitary with short and stout pedicels and they contain up to five stigmas while the hermaphrodite flowers are perigynous. The fruit has diverse shapes, ranging from club – like to cylindrical to spherical, with each fruit having as much as 100 – 400 seeds, the weight of 100 seeds being about 20 – 40g.The cucumber cotyledons are opposite and long elliptic with alternate euphylla which also alternate, simple, pentagonal palmate or cordate in outline having about 3 to 7 lobed blades. Cucumber has shallow root system which strETches mainly in the cultivated land layer of 30cm. The pistil consists of about one to five carpels which produce ovaries with equivalent number of locules.

2.1.4 Fruit Size and Shape

The length of the cucumber fruit varies depending on variety, from about 10 to 76 cm. In terms of shape, the cucumber fruit is cylindrical and elongated with tapered ends. When matured, it forms a bulge in the middle, changing in color from green to yellow, at this stage, it is not healthy for consumption (Redmond, 2007). It has been scientifically proven that cucumbers are fruit due to the presence of enclosed seed and being that it develops from a flower. They can however be considered and consumed as vegetables just like tomato and squash due to their bitter flavor. The fruit shape and skin appearance is highly affected by high and low temperature due to their sensitive nature, therefore, it is best if they are kept at 7 – 10°C and 85 to 95% relative humidity. (Thompson 2002) in air, 8 to 12°C in 1% to 4% O_2 and 0% CO_2 (Cantwell and Kasmire, 2002). If stored below this temperature, then the appearance, firmness (quality) and shelf life is going to be affected.

2.1.5 Economic and nutritional significance of cucumber

Cucumbers are essential vegetables consumed as food and used as well in medicinal applications (Schaefer & Renner, 2011). (Okonmah, 2011) reiterated the fact that it is among the commercial vegetables which contribute largely to sales in the tropical region. It is one of the extraneous vegetables grown in Ghana with high potential of being exported (Norman, 2003), in this part of the world, it can be eaten raw or used in preparing vegetable salad or stew (Sinnadurai, 1992). For this important vegetable / fruit, a 100g of the consumable portion is composed of 96% water, 0.5g of protein, 2.9g of carbohydrate, 0.6g of fibre, 0.1g of fats, 13kcal of energy, 14mg of calcium, 17mg of potassium, 4.7mg of ascorbic acid, 2mg of sodium, 0.30mg of niacin, 0.03mg of thiamine and 0.02mg of riboflavin (Maynard & Donald, 2000). From the statement of Paul & Raychaudhuri (2010), a lot of compounds with great medicinal potentials such as cucurbitins, cucurbitacins, cucurbitanes, urease, charantine, momordenol, momorcharins, insulin and polypeptide-P are used for humans and rats, and they are all isolated from cucurbits. One of these extracts (cucurbitacin), has an effective act of restraining the actions of cyclo-oxygenase enxynes which are responsible for inflammation (Dhiman *et al.,* 2012). Due to the presence of abundant water, nutrients and phytochemical composition in cucumber, its uses in culinary, therapeutic and cosmetic purposes cannot be over emphasized (Mukherjee *et al.*,2013; Muruganantham *et al.,* 2016)

Presently, after tomato, cabbage and onion, cucumber is the fourth most widely cultivated vegetable crop (Mukherjee *et al.*, 2013; Muruganantham *et al.*, 2016). Various benefits of cucumber have been confirmed from several nutritional and epidemiological researches. Cucumber has abundance of nutrients with a crunchy texture coupled with its unique flavour, it is therefore a very indispensable vegetable in a variety of dishes including salad and soup. It is rich in phytochemicals which has several various health benefits such as inducing weight loss, remedy for diseases such as: eczema, hypertension, chronic constipation, anti – inflammation, cardiovascular diseases and cancer (Oboh *et al.*, 2017). It has also been found to be a source of remedy for other diseases such as bad eyesight, scared mices, and scorpion bites. Kaempferol, a component of cucumber has been shown to be an important antidiabetic agent (Ibitoye *et al.*, 2018). It has also been discovered to revamp plasma lipid which also act as an analgesic (Abu-Reidah *et al.*, 2012). Abul *et al.* (2013) reiterated that cucumber juice is essential for healthy growth of the skin, complexion as well as anti-inflammatory properties.

As a cosmetic, cucumber serves a purpose in natural beautification and also for treatment of the skin, keeping it soft and white (Fiume *et al.*, 2014; Uzodike & Onuoha, 2009). Rahim *et al.* (2013) mentioned that women enjoy using cucumber on their faces as it cools the eye especially during summer, this is because it has an extremely cooling effect. The high level of vitamin K in this fruit helps in reducing cutaneous eruption such as puffiness and also dark shadows (Uzodike & Onuoha, 2009). Other significance of cucumber is related to it having a small genome, diploid, short life cycle and self – compatible mating characteristics which accounts for its suitability for genetic studies.

It has also been recognized by Huang *et al.* (2009) as a model plant for assessing sex determination and plant vascular biology.

Summarily, the health benefits of cucumber include:

- It supports digestive health due to its constituent of water and fibre
- It contains potassium which aids healthy heart
- It protects the skin against ageing
- It is low in calories thereby helping to maintain a healthy weight
- It is a great source of vitamin K which makes the bone strong
- Due to its contents of Flavonoids and tannins, it helps to relieve pain
- It contains vitamin B which helps in managing stress
- It helps to fight inflammation
- It protects the brain neurological disorder

2.1.6 Problems facing cucumber production in Ghana

In spite of the fact that cucumber does well in an environment with moderate light intensity, low humidity, high temperature, good textured and structured soils with stable water source and nutrient, cucumber farmers in Ghana still experience the problem of inadequate yield (Ameho, 2017a). As stated by Papadopoulos (1994), amongst the challenges of cultivation under conditions of high relative humidity (where water is in excess) is the incidence of diseases such as downy and powdery mildew. All species of fungi perform best at a temperature range of 22-27^{o}C and relative humidity of 96%, that is when at situations like this, the fungal spores are able to grow and germinate well (Babadoost *et al.*, 2004). The continued increase in population worldwide leads to increased competition for arable lands for human use such as shelter, creation of recreational centres, organic waste disposals, all these further increases the scarcity of land, limiting the area available for crop production and of course leading to reduction in yield (Ogbodo, 2012). As mentioned in FAOSTAT (2013), as compared to the 37.4 tons and 666.7 tons obtained in Morocco and Netherlands respectively, the productivity of cucumber in yield per hectare in Ghana was 12 tons.

For optimum cultivation of cucumber, the most suitable soil types required are sandy loams, loams or silty loams due to their high organic matter content. Soils in Africa, however, and Ghana for that matter are low in organic matter, a major factor contributing to the low yields obtained (Kelley *et al.*, 2000). Rainfall pattern in Ghana is unsteady resulting in water stress during most periods of the year, this affects nutrient absorption and translocation, hydration, photosynthesis, respiration, biochemical and metabolic reactions and afterwards low yield (Acquaah, 2005; Poincelot, 2003). Also, the fact that most cultivation of cucumber is done in the open fields affects its productivity, when cropped in these fields, they are exposed to several abiotic factors including fluctuating temperature (high and low temperature) and unfathomable weather. Even biotic factors are also a serious threat in these fields, incidence of downy and powdery mildew affects cucumber in severe ways. Therefore, to achieve efficient production of cucumber in these fields such that the size, shape, color and firmness would not be affected, special measures need to be put in place.

2.1.7 Site selection for cucumber production

Cucumbers grow well on soils with good drainage and adequate water holding capacities, they however do best in loose sandy loam soils. They require full sunlight for adequate growth. They don't perform optimally on acidic soils, rather they do well on soils which are slightly acidic in nature and with P^{H} ranging from 5.5 – 7.0. They are not usually planted close to tree roots because their roots reach up to 91 to 122 cm deep and these tree roots will compete with them for water and nutrients. During the growing season, they require a regular supply of moisture as moisture fluctuation can result in deformities in growth thereby reducing both the yield and quality of the crop. Due to their sensitivity to cold, they can be injured by as little as a slight frost. They grow well at temperatures between 18°C and 35°C as any temperature below 10°C and above 35°C can lead to slow growth and maturity of the crop.

2.2 GREENHOUSE

2.2.1 Definition, characteristics and importance of greenhouse

Greenhouse cropping is a practice whereby crops are raised in an isolated structure. Practice of greenhouse cropping is a fast growing sector of agricultural production globally, this is associated to the favorable and controlled climate provided to the plants when this system is utilised, thus increasing the rate of plant growth and development (Coleguwor, 2018; Thipe *et al.*, 2017). With this technology, plants are protected from adverse weather conditions, both the biotic and abiotic factors (Reddy, 2016). Recently, as stated by Hassanpour *et al.* (2013), this technology has increased employment rate through production of agricultural crops that are off – season by efficient management of growth media, water and space.

The design of the greenhouse is such that it has walls plus a roof usually made with transparent structures including glass and plastic, these structures provide plants with the required regulated climate during production and help against the adverse effects of external environmental condition (Sharma *et al.,* 2013). The advent of greenhouse cropping in Ghana was started by Prof. George Oduro Nkansah in 1996 and since then, the practice has been establishing rapidly in a good way. This technology has been found to enhance food security in Ghana, it is also an efficient way of getting youths to participate in agriculture, thus creating more force in the farming system and ultimately leading to productivity increase in greenhouse production.

From the observation of Elings *et al.* (2015), making use of greenhouse in vegetable production is on a low level, he thus suggested more work in this aspect.

2.2.2 Greenhouse Cucumber Production

Cucumber is one of the common major vegetables cultivated under greenhouse conditions and its effective development under this condition contributes to its profitable production (El-Wanis *et al.,* 2012; El-Zawely & El-sawy, 2007). The major reason for development of greenhouse as stated by Hasandokht (2005) is to enhance productivity and water intake efficiency. He further stated that efficiency of water intake can be made possible in two ways: making production level same but with reduction in water consumption and by leading to yield increase in return for the consumptive water use through stem diameter, leaf area index and product weight.

It grows productively under conditions of high humidity, high light, fertilizers and moisture in plastic greenhouses (El-Zawely & El-Sawy, 2007). Globally, the utilization of controlled environment such as greenhouse in vegetable production is been given increased attention as demand for fresh vegetables all year long is on the high side coupled with the need for safe pest and disease control techniques. It was therefore shown from the work of Gruda (2005)that sustainable supply of these safe vegetable crops to meet the increasing demand entails the use of greenhouse.

Greenhouse production is used in many tropical areas of the world in the production of vegetable (DeGannes *et al.*, 2014).

Blanco & Folegatti (2003) mentioned that when crops are grown in the greenhouse, especially during the autumn – winter season, development is better as higher temperature is experienced from the cover it provides, this promotes cultivation and thus increasing profitability.

Growing crops in the greenhouse has many benefits some of which include: modifying light intensity, atmospheric relative humidity and temperature regulation thereby protecting crops from adverse climatic conditions, increasing profitability of production by providing optimum growing condition thereby enhancing plant growth and development and increasing yield and good quality produce (Aldrich & Bartok, 1989; Elings *et al.*, 2015), off – season production of crops resulting in higher market price (P. Kumar *et al.*, 2015), protection of crops from unfavorable climatic conditions, reduction of pest and diseases activities (Gonzalez *et al.*, 2014), increased water and nutrient uptake, rapid vegetative and reproductive growth rates and large root masses (Sutherland, 1988). In Ghana especially, adoption of greenhouse technology in crop production will have a significant impact in the agricultural sector.

Shade is important in production as it regulates the intensity of light getting to the plants thereby reducing temperature and increasing the relative humidity leading to reduction in evapotranspiration rate (Hashem *et al*., 2011; Siwek & Lipowiecka, 2004).

From the observation of Choi *et al.*, (2001), the height, fresh weight and dry weight of plants grown in a closed system such as the greenhouse were higher as compared to those cultivated in an open system.

2.3 IRRIGATION

2.3.1 Definition and importance of irrigation

The artificial application of water to a growth medium with the aim of meeting the plant's water demand during the different growth stages is referred to as irrigation. Water can be diverted from streams, lakes, reservoirs, aquifers or rivers and left to flow by gravity or pumped in some cases to the point of need. With irrigation, the quality, reliability and quantity of production is usually enhanced (Bjorneberg, 2013).

All over the world, water serves as a highly important ingredient in sustainable agricultural production. Its availability serve as a basic limitation to arable crop production, for example, in regions with little rainfall, irrigation is very essential and even those with enough rainfall, irrigation becomes necessary during the dry season in order to meet up with the needs of the ever – growing population (Zakka *et al.*, 2020).

Over time, different methods of irrigation have been developed in order to meet the irrigation demands of different crops in different areas. There are thus three basic methods and they include: Surface, sprinkler and drip or micro - irrigation method (Bjorneberg, 2013).

Surface irrigation method is an irrigation method whereby water is left to flow over the soil by gravity. Depending on location however, water may require been pumped from the source to the field due to high elevation, although in most cases, supply occur by gravity through pipes, canals or ditches. It is suited for crops ranging from orchards, pastures and field crops.

Surface irrigation is of three basic types which are: basin, furrow and border irrigation. Based on crop type, land slope, soil type and management, the efficiency of this irrigation system varies significantly. It has also been found to be of lower efficiency as compared to sprinkler and drip irrigation systems, owing to the fact that the soil and not a pipe usually serves as the conveyance system in its own case. If well managed however, it can give an application efficiency of up to 90% as stated by Bjorneberg (2013).

Sprinkler irrigation is an irrigation type whereby water is applied to the soil by spraying of droplets of water through air from a system which is either a fixed type or moving type

Water delivery to the system is usually through a pipe system which is mostly buried in order to avoid interference with other actions taking place on the field. It is suited for crops such as: vegetables, pastures, field crops, turf and orchard.

There are three main types of sprinkler irrigation systems which include: solid-set, set-move and moving systems. The solid-set systems for example are capable of being buried in the field for up to a season in the case of some field crops, they can even be installed permanently for crops such as orchards and turf. The moving system example is the center pivot systems, water is being applied as it moves from one end to another through the field. As for the set – move systems, they can be moved in a manual way from one part of the field to another until the field is completely irrigated.

In comparison to the surface irrigation systems, these systems are more efficient as there is more control over water application. One of the disadvantages associated with these irrigation systems however is the resultant water loss that occurs due to evaporation and wind effects both during hot weather and windy situations respectively.

Drip irrigation is a method of irrigation whereby water is transported under tension via the means of pipes to the point of use, it goes slowly into the medium through drippers fixed closely to the plant. This irrigation type is suitable for use on any land slope and irrespective of the soil type.

With drip irrigation, as compared to the surface and sprinkler irrigation systems, water only gets to the plant's immediate root zone where it is needed only with little losses involved (Zakka *et al.*, 2020). It therefore serves as a very effective irrigation method for most crops.

Bjorneberg (2013) also described a minor irrigation type referred to as sub – irrigation method in which the water table has been lifted close to the root zone of the plant by making use of sub – surface drains or ditches for water supply.

2.3.2 Drip Irrigation and Cucumber Production

Cucumber is one of the major vegetable crops grown in Ghana due to its major benefits ranging from culinary to therapeutic to medicinal benefits, it has high sensitivity to water stress, it is therefore of high importance to take into consideration its water needs if higher yield is to be obtained (Hasandokht, 2005).

As it is, the major factor affecting agricultural development in arid and semi – arid regions is access to water (Tabatabaei *et al.*, 2011), making use of methods that help manage irrigation, that is;

improvement of crop water use efficiency (WUE) is therefore a necessary action, especially in areas where water scarcity is an issue (Gençoğlan *et al.*, 2006)

Balliu (2017) stated that, the most convenient method for growing of cucumbers is the drip irrigation method. He further emphasized that, when sprinkler irrigation is used, it gives rise to incidence of fungal disease and when furrow irrigation is used, it can encourage lodging of plants due to lack of control over water leading to over – irrigation.

When selecting source of water for irrigation, it is important to take into consideration the EC and pH. EC of less than 1 dS/m and a slightly acidic pH is recommended. In a case where the medium is saline in nature, the irrigation can be increased so as to leach out the soils (Balliu, 2017).

For good yield of cucumber crop, optimum moisture and temperature are a prerequisite, as without these, problems such as: mineral disorders, fruit - growth delay and reduction of female flowers are likely to be encountered (Cantliffe, 1981; Liebig & Krug, 1989; Marcelis & Hofman-Eijer, 1993; van den Broek *et al.,* 1988).

2.3.3 Cucumber and Irrigation Requirement

Cucumber has a sparse root system, due to this, it becomes imperative to understand its water requirement as about 85% of the root length occupies the upper 30 cm top layer of the substrate (Janoudi & Widders, 1993).

Cucumber requires a steady supply of water in order to give high quality and yield. This is especially important during growth stages such as the seed germination stage, flowering stage and fruit enlargement stage. Due to its high water requirements, cucumber generally has a high irrigation frequency (Balliu, 2017).

Its daily water requirement is dependent on factors such as: relative humidity, light intensity, plant density, temperature and phenological stage.

Greenhouse cucumber crops especially have a high water demand as compared to those grown on open fields (Loomis & Crandall, 1977).

Reference Evapotranspiration (ETo)

It is the evapotranspiration that occurs with respect to a reference surface.

There are four methods of estimating reference evapotranspiration, they include: Blaney-Criddle, Penman-Monteith, Pan evapotranspiration and Radiation method. With regards to use of meteorological data, the basic approach for this estimation is the Penman-Monteith method, making use of the equation:

$$ET_o = \frac{\{0.408\Delta(Rn-G)+\gamma\frac{900}{T+273}U2(es-ea)\}}{\Delta+\gamma(1+0.34U2)} \quad \text{……………………………………..….Equation 2.1}$$

Where:

ETo = Reference evapotranspiration (mm/day), Δ = Slope of saturated vapour pressure against temperature curve (kPa/^{o}C), Rn = Net radiation at the surface of the crop (MJ/m^2/day),

G = Heat flux density of soil (MJ/m^2/day),T = Average daily air temperature at 2m height (^{o}C),

U_2 = Speed of wind at height of 2 m (m/s), e_s = Saturation vapour pressure (kPa),

e_a = Actual vapour pressure (kPa), $e_s - e_a$ = Saturation vapour pressure deficit (kPa),

γ = Psychrometric constant (kPa / ^{o}C)

Crop Water Requirement (ET_c)

The amount of water required to meet the evapotranspiration needs of crops is referred to as the crop water requirement. Estimation of the amount of water required for plant during the growth period is a prerequisite in planting, as it is very crucial in developing the suitable irrigation schedule required to optimize plant yield (Sahin *et al.*, 2015). Depending on location however, plant irrigation requirement varies consistently as the rate at which they take in water depends on stage of growth, climatic conditions and type of growing medium (Uçan *et al.*, 2007).

Sahin *et al.* (2015) mentioned that, in the open field, the water requirement of crops are usually determined by making use of the pan evaporation or Penman-Monteith method. He also noted that the most used method in this determination is the evaporation pan method due to the ease of obtaining data and cheap cost involved.

Due to challenges associated with direct measurement of ET_c such as time consumption amongst others, the CROPWAT model is mostly used in the estimation nowadays. This model is a computerized one fabricated by FAO to assist in computing of crop's water and irrigation requirements and also designing of irrigation schedules (Smith, 1992). It makes use of a combination of climate, soil, crop, rainfall and irrigation parameters in making a water balanced model as pointed out by Allen *et al.* (1998). It was stated that this method of estimation agricultural water demands makes use of ET_o and deductions from rates of crop evaporation, referred to as crop coefficient .

$ET_c = ET_o \times K_c$……………………………………………………….Equation 2.2

Where:

ET_c is the crop evapotranspiration, K_c is crop coefficient and ET_o is the reference evapotranspiration (mm/day).

Net Irrigation Requirement (IRn): The IRn is the quantity of water required to be received by the crop via an irrigation system, thereby ensuring complete provision of water need throughout the growing period (Doorenbos and Pruitt (1984). During this estimation, losses encountered during the process of water application are not usually considered. Savva & Frenken (2002) reiterated that error during IRn estimation can result in significant problems in the irrigation system and also waste of water.

$IR_n = ET_c – (Pe + Ge + Wb) + LR$ …………………………………….………..Equation 2.3

Where:

IR_n = Net irrigation requirement in mm, ET_c = Crop evapotranspiration in mm,

P_e = Effective rainfall in mm, Ge = Groundwater contribution from water table in mm

LR = Water stored in media at commencement of each period in mm

LR = Leaching requirement in mm

Gross Irrigation Requirement: This represents the net irrigation plus net water and operational losses during water application (Doorenbos & Pruitt, 1977; Savva & Frenken, 2002). That is, all water losses encountered through conveyance to application is part of IR_g.

$IR_g = \frac{IRn}{Ea}$ ………………………………..……………………………… Equation 2.4

Where:

IR_g = Gross irrigation requirement (mm), IR_n = Net irrigation requirement (mm),

E_a = Field application efficiency

2.3.4 Distribution efficiency: Knowledge of distribution uniformity of a drip emitter helps in detecting areas that likely to not get enough water and develop ways to take care of them. With appropriate procedure followed, the proportion of the ununiform distribution will be known as it is depicted by the amount of the average application quantity applied at the lowest quarter of the experimental site (Rogers, 1997). Determination of the distribution uniformity of an emitter discharge requires four major indices, these include: DU, QV and CV. Where DU is the distribution uniformity, CV represents the coefficient of variation, QV is the variability in emitter flow. For the purpose of irrigation, DU estimation as expressed by United States Department of Agriculture (USDA) around 1940 involved the use of the proportion of the lowest quarter (dlq) (Burt *et al.*, 1997).

$DU = \frac{Qlq}{Qa} * 100$…………………………………………………………..…….Equation 2.5

Where: DU = Distribution uniformity. Q_{lq} = observed mean rate of discharge of lowest quarter (l/hr), Q_a = observed mean rate of discharge of the entire field (l/hr).

2.3.5 Irrigation Scheduling

Irrigation scheduling is a very important factor that should always be taken into consideration as over – irrigation is likely to affect yield negatively and under irrigation leads to water stress in addition to its negative effect on yield (Locascio & Smajstrla, 1996).

The ratio of crop yield to seasonal water use is referred to as water productivity whereas irrigation water productivity deals with the ratio of crop yield to a particular treatment to the water applied for that treatment. Optimum scheduling of irrigation by making use of water use patterns and response of crop to water deficit helps improve both the WP and IWP (Ali & Talukder, 2008). When the threshold level for a medium is known, proper irrigation scheduling helps maintain this level by ensuring that the moisture deficit doesn't get to that level for a given crop and substrate. To make this efficient, it might therefore be necessary to determine the earliest and latest date for irrigation thereby leading to efficient irrigation and reducing water stress effects respectively (EI-Kazzaz, 2017).

Although irrigation amount does not depend solely on type of substrate, Irrigation frequency however depends on type of substrate and prevailing weather conditions (Balliu, 2017). In terms of the soil – based medium, light - sandy soils for example require consistent irrigation with little water on each occasion due to their characteristics of rapid moisture loss, whereas for clay soils, the interval between one irrigation event to the other is more than that of sandy soils because they have more micropores which is able to retain water and release to plants over a period of time.

For appropriate irrigation scheduling, some factors need to be determined, these include:

Soil Water Availability: This denotes the ability of a growth media to hold water and avail it to the plants. After an irrigation or a rainfall event, the quantity of water left in the media after drainage represents the field capacity. The higher the moisture retained in the media, the higher the proportion available for plant use. Available water content is thus the quantity of water to be applied to a soil media at wilting point to bring it to field capacity (Allen *et al.,* 1998).

Total Available Water (TAW): The TAW in a plant rooting zone is a function of the field capacity and wilting point. It connotes the total moisture available to a plant, it is variable dependent on factors including media organic content, texture and structure as pointed out by Doorenbos & Pruitt (1977).

This was estimated from the formula:

$TAW = (\Theta_{FC} - \Theta_{WP}) * Z_r$ ……………………………….………………………Equation 2.6

Where:

Z_r = Depth of crop root zone (mm) (Doorenbos & Pruitt, 1977)

Θ_{FC} = Field capacity moisture content (%)

Θ_{WP} = Wilting point moisture content (%)

Readily Available Water (RAW): At permanent wilting point, water in the growing media is not readily available to soil due to the low quantity, this gives rise to the term "readily available water " which is the quantity of media moisture that is easily accessible to plants at all periods. It is the proportion of the available water that the plant can utilize without any going through moisture stress.

The formula for calculating RAW as given by Allen *et al.* (1998) is:

$RAW = (\Theta_{FC} - \Theta_{WP})\ P * Z_r$ ………………………………………………………… Equation 2.7

Θ_{FC} = Field capacity moisture content,

Θ_{WP} = Wilting point moisture content,

P = Proportion of soil moisture content capable of being depleted from the root zone prior to moisture stress and yield reduction,

Z_r = Depth of crop root zone

Irrigation Interval: This represents the longest period before which the next irrigation must take place. As proposed by Misra & Ahmed (1990), maximum irrigation interval is calculated thus;

$T_{max} = \frac{AMD}{ETc}$ ……………………………………………………………………………Equation 2.8

Where:

T_{max} = Maximum irrigation interval in days

AMD = Allowable soil moisture depletion in cm

ET_c = Daily water use (cm/day)

2.4 GROWTH MEDIA

A growing medium is any material, in which plants are grown. It supplies air, nutrient and water necessary for plant root and shoot growth and increased yield and quality of produce (Nelson, 1991). For production of quality crops, it is necessary to utilize a suitable growing media as it determines, to a great extent, the development of the extensive functional rooting system of the plant.

According to Bilderback *et al.* (2005) the growing media functions in plant growth and development can be summarized into three, these are:

a. Provision of air and water
b. Provision of physical support
c. Enhancing maximum root growth

These media also perform significant roles on height, initiation, growth and value of ornamental plants raised in a container(Vendrame *et al.*, 2005). Bilderback *et al.* (2005) recommended that growing media should be characterized by large particle sizes with adequate pore spaces between the particles, as this is essential for a light and well – aerated medium so as to ensure fast seed germination, adequate drainage and good root growth.

A variety of ingredients have been utilised in producing growing media for vegetable production, but, according to Schmilewski (2008) based on their local availability, the raw materials utilised vary. With this therefore, the growing media can be of both organic and inorganic origin (Olle *et al.*, 2012). Some of the organic ones are: coconut coir, compost, peat, poultry feathers and tree barks whereas the inorganic ones include: vermiculite, clay, mineral wool and perlite (Grunert *et al.*, 2008; Vaughn *et al.*, 2011). These media can be used alone or in combination to provide the required nutrient, air, water and support for plant growth (Noto, 1993).Examples of the combination include a mixture of coir and clay, peat and perlite, peat and compost (Nair *et al.*, 2011). Growing media can be classified into two, namely: the soil based and the soilless growing media (Spiers and Percy, 2007).

2.4.1 Components of growing media for greenhouse production

Growing media for containerised production in greenhouses are usually composed of a number of soilless ingredients including vermiculite, shredded coconut coir (husk), perlite, peat moss, composted materials. For this purpose, it is not encouraged to make use of field soils as they do not give satisfactory result during containerized production as they do not provide adequate aeration, drainage and water holding capacity which are all essential for optimum plant growth. In addition to this, making use of soil comes with stress as there will likely be a need to fumigate to reduce weeds and disease infestation.

These media are usually designed to give high water retention, porosity as well as aeration. The recommended pH for greenhouse crops ranges from 5.8 to 6.2. If acidic, the pH can be corrected by adding limestone (calcium and magnesium carbonates), thereby also making Ca and Mg available for plant uptake. Limestones with smaller particle sizes work faster in increasing the substrate pH as compared to those of larger particle sizes. Alkaline pH of the medium can however be corrected by adding Sulphur to the medium.

More than 50% of commercial greenhouses make use of 30 to 50% peat moss, either alone or mixed with composted pine bark. At most times, materials such as perlite and vermiculite are added to increase aeration improve water holding capacity.

In a statement made by Hseih & Hseih (1990), one of the ways in which agricultural wastes can be managed properly is by bringing them back into the system to serve as soil improvement thereby enhancing the properties of degraded soils by improving the organic matter content amongst other benefits.

As population keeps increasing, potentials have been seen in agricultural residues as growing media source for greenhouse production. They are obtained at low or no cost, easily accessible and can even be reused. The production of these wastes worldwide annually has exceeded 500 million tones, and from the work of Quartey (2019) & Sánchez (2009), more than 4.2 million tones of Agricultural wastes are produced in Ghana on a yearly basis.

Gungula & Tame (2006) have pointed out that one of the major practices in nursery management and nurturing seedlings in greenhouse nowadays is making use of alternative substrates other than soil, these substrates may include: rice husk and saw dust amongst others. Selecting a soilless growing media for sustainable crop production is however dependent on factors such as accessibility, price and properties of the media (Lieten *et al.*, 2004).

Researches has shown that agro industrial wastes such as rice husks, cocopeat, cocoa pod husk, leaf mulch, kola pod husk and so on are often employed as growing substrates in raising crops (Adejobi *et al.*, 2011). These materials are easily accessible, cheap, and still yet contain various nutrients, they can therefore be used as soilless media for growing plants sustainably (Z. Khan *et al.*, 2012). Adamtey (2005)further pointed out the importance of these agro – industrial wastes stating that wastes such as rice husk, cocoa husk, saw dust, coconut shells, palm frond and sugarcane bagasse, when worked on, can be of high relevance in crop production due to their essential nutrients components including: nitrogen, phosphorus, potassium and magnesium.

2.4.2 Soil based growing media

Soil is the most common and easily accessible growing medium used for crop production. It is a mixture of solid particles (mineral and organic material), water, air and organisms. Plant growth is dependent on six major factors: light, mechanical support, water supply, nutrient supply, oxygen supply and heat. All of these factors except for light are provided by the soil to the plants as its roots go deep into the soil for water, air and nutrients, hence the soil is referred to as a natural medium for plant growth. When the plants root penetrates the soil, the soil provides it with support by making it firm, the heat provided, warms up the soil thereby aiding rapid litter decomposition which aids nutrient cycling leading to faster release of nutrients.

Of all the growing media, it is the heaviest with a low organic matter content which accounts for its low water holding capacity (Khan *et al.,* 2002).

2.4.3 Challenges Associated with the Use of Soil - Based Growth Media

As compared to field conditions, plants raised in the nursery can only have access to a limited portion of the soil, that is, depending on the container size. This means that the seedlings can only get little amount of available water and nutrients, with addition to the fact that these amounts changes rapidly. Because of this, therefore, it is necessary to provide a medium of the best possible material for the plant.

Imbalance of soil microorganisms is another challenge of using soil based medium in the greenhouse. These microorganisms are either beneficial or pathogenic and they occur in a natural balance in the field, when the soil is however transferred to the greenhouse, this balance is affected and problems might arise. For example, when irrigation and fertilization is done frequently, it enhances the growth of these organisms, hence increasing competition with the plants

One of the challenges with planting crops on soils in greenhouses is the occurrence of soil – borne diseases, these diseases are capable of reducing yield and quality of produce (El Sharkawi *et al.*, 2014). To manage these diseases, some chemicals are needed, these chemicals however, are costly and require technical skills (Elings *et al.*, 2014). Cucumber growth, yield and quality, for example is negatively affected by the Fusarium wilt disease (Cohen *et al.*, 2015). Controlling this disease is a complicated process as they can survive as chlamydospores for a long period in the soil and can live as a saprophyte to continue to exist (Sun *et al.*, 2015; Agrios, 2005).

Other soil borne diseases which can result from growing crops on soil under the greenhouse include root rots, root knot nematodes, nematode – transmitted diseases and root wilts (Van Bruggen and Semenov, 2015). In many cases, when crops are grown on the soil, there is risk of soil salinity problem being encountered as excess nutrient levels might result from previously grown crops.

Soils, naturally, are variable depending on location and depth in the profile, maintaining the same quality from container to container, crop to crop and year to year is therefore, not an easy task, as it might not be achievable, thus making production difficult.

Also, when greenhouse crops are grown on soil, factors such as temperature variations, absence of available nutrient, low cation exchange capacity, difficulty in disease and pest control and low cation exchange capacity amongst others are mostly a problem (Du Plooy *et al.*, 2012).

Soils usually contain weeds which compete with the plants for water and nutrients, this increases the work of the farmer who might needs to spend more on labour.

Asides from this, Landis (1995) reiterated that containerised native soils do not provide the required amounts of nutrients needed by plants for rapid growth in addition to the fact that some certain nutrients are rendered immobile. With clay soils, nutrients are rendered unavailable to plants, while with sandy soils, nutrients are loosely held resulting in losses through leaching.

Although soil as a medium for plant growth is mostly generally available, limitations such as erosion, problem of compaction, incidence of nematodes and pathogens which all have a negative impact on the plant development and quality cannot be overlooked (Beibel, 1960).

Also, with regards to soil texture and particle sizes, clay and silt soils for example, are characterised by very small particle sizes and few air spaces making them heavy and reducing the rate of drainage out of the container, this condition is unfavorable for plant growth. As for sandy soils, they have large particle sizes which release water freely out of the container without giving the plants maximum time to utilize it.

2.4.4 Soilless Growing Media

Soilless culture is an artificial means that involves provision of plants with anchorage and reservoir for water and nutrients. Any method of raising plants without utilizing soil as a rooting medium can be referred to as a soilless plant culture (Savvas *et al.*, 2013). Crops are cultivated without the use of soil, supplying water and nutrients to the plants through fertigation. That is, with soilless cultivation, there is improvement in water and nutrient management. This method can be used in growing almost any kind of plant, including veggies, fruits, herbs and flowers (EI-Kazzaz, 2017). It has been used successfully in growing vegetables (such as lettuce, cucumbers, tomatoes, melons eggplant, spinach and peppers), ornamental crops (such as roses, foliage plants, and roses) and even fruit crops such as raspberries and strawberries).

Mazahreh *et al.* (2015) summarised the aims of this cultivation method to include: increased yield and quality of produce, land maximisation and labour maximisation.

Making use of soilless cultivation has many benefits, some of which include: uniform water and nutrient application to plants, increased yield and quality, good plant growth and development, elimination of need for disinfection, and absence of soil – borne pathogens (Burrage, 2014; Savvas *et al.,* 2013). Quite a number of soilless culture techniques have been discovered and utilised commercially for production of horticultural crops including vegetables, even under greenhouse conditions. Soilless are classified as either being organic or inorganic(Grunert *et al.*, 2008; Vaughn *et al.*, 2011; Verhagen & Blok, 2007).

In soilless media production of crops, organic or inorganic materials can be used and nutrients are applied to plants in solution form, thereby ensuring efficient use of the resources and increasing yield and quality of crop vegetable production in the greenhouse (Dorais *et al.*, 2010; Goto *et al.*, 2013)

Another key area where soilless cultivation plays an important role is in attaining some of the Sustainable Development Goals (SDGs). The SDGs, also known as the global goals, were adopted by the United Nations in 2015 universally so as to end poverty, protect the planet and ensure that all individuals enjoy peace and prosperity. Enhancing sustainable food production, therefore, plays a major role in achieving some of the SDGs. By adopting soilless cultivation, the aim of putting an end to poverty and hunger by the year 2030 can be achieved, especially in developing countries including Ghana. The goals including:

1. No poverty.

2. Zero hunger

3. Good health and well – being

8. Decent work and Economic growth,

15. Life on land; further reiterates how much enhancing sustainable agriculture would promote livelihood by the effects on technological advancement. With these goals, the climate change issue has been addressed, there is improvement in global security and the world is gradually becoming what we want. With soilless farming, the three pillars of sustainable development including the social, economic and environmental aspects are taken care of, to an extent. As reported by FAO (2018), Sustainable food and agriculture plays a key role in revitalizing the rural landscape, ensuring inclusive development to countries and also enhancing positive change across the 2030 agenda.

2.4.5 Soilless as an Alternative to Soil for Production in Greenhouses

Researches have proven that crops cultivated on soilless media are better in terms of yield and quality of crops and flowers as compared to the soil based grown crops (Ahmad *et al.,* 2012; Ghehsareh *et al.,* 2011).

In many countries, the use of soil in greenhouses has been replaced with the use of soilless media, this according to (Butt, 2001) is due to diverse reasons including, slow release of soil nutrients to the crop, delayed maturity and ripening of crop, soil contamination, low yield and the difficulty associated with pH and EC control of soil.

The practice of soilless cultivation in greenhouse vegetable production is not something new as reported by Carlile *et al.* (2015). This practice is encouraged as it gives rise to crops with higher yield and quality in an environment that is less polluted. As compared to the soil – based agriculture where farmers utilize fertilizers in order to increase productivity and pesticides to control pests and weeds, soilless media grown crops are more protected from weeds and pests. They also help to suppress soil – borne pathogens (Hadar, 2011).

Also, the problem of monoculture of crops for a number of years on a particular land is eliminated (Fecondini *et al.*, 2011), and better control of plant nutrition is ensured as well as elimination of plant diseases which are encountered when soil is used as a medium even in vegetable crops such as cucumber, tomatoes and pepper (Olympios, 1992).

Also, p^H, EC, temperature, water and nutrient availability are more efficient and controlled according to the crop requirement and greenhouse conditions giving higher yield and quality of produce. Resh (1997) buttressed this fact in a statement where he compared greenhouse vegetable soilless production to greenhouse production in soil and under traditional open field conditions, that when vegetable is produced under soilless cultivation in the greenhouse, effective use of water and nutrients is maximised.

According to Chalhoub *et al.* (2013), with the utilization of soilless media, water retention is enhanced increasing the amount of water available to enhance plant growth. The soilless materials are also easier to manage and have been found to provide a better growing environment for plant growth and development (Mastouri *et al.*, 2005), that is; there is adequate control of the plant environment and problem of uncertainties which occur when plants are grown on soil is avoided.

With soilless culture, plant nutrition is more controlled as compared to the soil - based culture, that is, the utilization of water, fertilizer and labour is controlled, environmental regulations against groundwater pollution with pesticides and nitrates is also in place.

As summarized by (Burrage, 2014; Savvas *et al.*, 2013), the advantages of soilless over soil – based media to include:

a. Efficient nutrient and water application
b. Increase in output independent of climatic conditions
c. Reduction in pollution by nutrients and pesticides
d. Efficient control of pest and diseases
e. Reduction of soil – borne pathogens
f. No need for soil sterilization using chemicals
g. Efficient use of fertilizers and pesticides

There are different kinds of materials that can be used as soilless media and some of them are:

2.4.6 Charred Rice Husk

Rice cultivation is practiced in more than 75 countries worldwide, the chief among them being China. Hu *et al.* (2020) mentioned that, annually, rice production is estimated to be about 770 million metric tons with the husk constituting more than 10%.

Rice husk is a by - product of the rice milling industry. It is the hard shell which covers the rice grains, it is usually separated from these grains during milling, thus revealing brown rice where the bran is later removed to give the white rice which is consumed. During grain development, it provides nutrients and helps in accumulation of metabolites, it also serves as seed protection against physical damage and other damages including insects, pests and pathogens attack. It is found abundantly as a waste material in all rice producing countries. It is therefore easily accessible and of low price in these countries, making it of extra benefit.

Awang *et al.* (2009) characterised rice husk as being cheap, easily accessible locally, easy to dissolve in water, having a granular composition, high in mechanical strength and highly stable.

Of the weight of paddy rice, rice husk makes up about 20% and it has a chemical composition including: organic carbon (30 – 50%), cellulose (40 – 45%), lignin (25 – 30%), moisture (8 – 15%) and ash (15 – 20%) (Ismail & Waliuddin, 1996); this ash is basically silica as it contains around 87 – 97% silica, accounting for its high porosity, light weight, and high external surface area. Other composition of rice husk include: bulk density of 90 – 150kg/m^3, oxygen of 31 – 37%, nitrogen of 0.23 – 0.32% and Sulphur of 0.04 – 0.08%. It also contains K_2O, Al_2O_3 CaO, MgO, Na_2O_3, Fe_2O_3 but not up to 1%.

According to Hirschey (2003), rice husk is often used as compost, as mulch or even mixed with soils thereby improving aeration and water holding capacity which invariably means high yield and production of good quality produce.

Depending on the rice variety, prevailing temperature, soil and climatic condition, agricultural practices of fertilizer and insecticide application and so on, the silica content in the rice husk varies. Contrary to their extremely light weight, they are effective at drainage improvement, their good chemical and physical properties (Awang *et al.*, 2009).

Charred rice husk (CRH), just like rice husk, is highly abundant in rice – producing countries. It is the result gotten from rice husk combustion. Among all plant residues, it has the highest silica content (about 85 – 90%) (Chan & Xu, 2012; Yalcin & Sevinc, 2001). It is rich in nutrients such as silica and potassium, and when mixed with soil, it increases the rate of moisture and nutrient retention. In addition to this, CRH removes odor from the root system thereby contributing to its hygiene.

Charring of rice husk gives rise to many advantages including: increased water holding capacity, increase in carbon content and sterilization of media (Oshio *et al.*, 1981).

The characteristics of CRH are dependent on:

a. The composition of rice husk
b. Burning temperature and
c. Burning time

Haefele *et al.* (2009) & Hartmann *et al.* (1997) highlighted the characteristics of CRH as follows:

a. Bulk density of about 0.150g/cm3
b. Highly porous structure
c. Very light weight
d. Ease of water drainage
e. Resistance to decomposition

According to FFTC (2001), When CRH is mixed with soil, there is resultant increase in pH, leading to increase in available phosphorus (P), levels of exchangeable potassium (K) and magnesium (Mg)

2.4.7 Cocopeat

Otherwise referred to as coconut coir, ultrapeat and cocotek is an agricultural by – product completely organic in nature and obtained after fiber has been extracted from the coconut husk (Abad *et al.,* 2002). The coconut long fibers are utilised in manufacture of materials such as car seat, brushes, mattress stuffing, whereas its short fibers (2mm or less) are usually cut, crushed and then washed to give a new result which can be used as a medium for plant growth.

According to researches done in Kenya, Cocopeat has been used as a growing substrate to obtain the best results (Gechemba *et al.,* 2015; Ketter *et al.,* 2013; Kipngeno *et al.,* 2015). It is highly recommended for raising seedlings in the nursery due to its light weight (Datta *et al.,* 2022). Its other benefits are, having a soil conditioning effect, serving as a compost filler and helping to retain moisture.

Cocopeat has been widely employed as a growing medium in producing a great number of crops with acceptable quality in the tropics (Yahya *et al.,* 1999). It has the property of water retention similar to vermiculite and air retention similar to perlite. It has a good electrical conductivity, pH and other chemical attributes (Abad *et al.,* 2002). Its properties can be summarized into:

- High water holding capacity
- Biodegradable, organic and non – toxic nature, making it environmentally friendly and easy to dispose after use
- Physical resiliency, that is; it has high ability to withstand compression as compared to other materials such as: sphagnum peat
- Slow rate of decomposition

- Easy wettability
- Excellent drainage property
- Acceptable pH, electrical conductivity and cation exchange capacity
- Absence of pathogens and weeds

However, depending on source, processing technique and handling, the physical and chemical properties of cocopeat vary widely (Evans *et al.*, 1996; Noguera *et al.*, 2000).

As compared to other media, cocopeat as a growing substrate has been found to perform better in growing ornamental plants (Abad *et al.*, 2002; Cantliffe *et al.*, 2007).

As reported by Ma and Nicholas (2004), in areas where there is poor quality control, coir with excess salinity and phenolic compounds is often problematic. Leaching of the coir with fresh water before use is an important procedure as it has been reported that some sources contain chlorides at concentrations toxic to many plants.

From the work of Evans *et al.* (1996), the physical and chemical properties of cocopeat from most supplies were usually of tolerable values asides from the chloride levels and electrical conductivity which were found repeatedly to be above recommended levels.

2.4.8 Challenges Associated with the Use of Soilless Growth Media

Although it has many advantages, the few drawbacks associated with the use of soilless growth media cannot be overlooked (Sonneveld, 2000). In utilizing soilless growth media, high degree of management skills is required especially in areas including disease prediction and control, preparation of nutrient solution, pest management, environmental control and maintaining optimum pH and electrical conductivity (Van Os *et al.*, 2002).

Cocopeat obtained from coconuts grown in coastal regions or those rinsed in saline water, for example, are capable of releasing phytotoxic degrees of sodium and potassium when they are utilised (Nichols, 2013; Schmilewski, 2008).

The utilization of cocopeat for example, has some limitations which include (Datta *et al.*, 2022):

- Due to its composition of natural salts, it is imperative to use that of high quality, it is also not advisable for recycling hydronic systems due to the same reason.
- It has high porosity and might therefore be of low support to the plant weight, leading to the introduction of plant supports.
- There is increase in cocopeat of poor quality in the market due to its relatively high demand.
- It is of light weight and only appropriate as a medium for small plants, if used for big plants, probability of being uprooted in the presence of high wind speed is high.
- If not used after few months of its production (compressed cocopeat), the ease of wettability and reuse will likely be affected, it is best, therefore, to make use of the freshly compressed one.

Asides from the fact that it takes a long period for coir to be stabilized, before it can be comfortably used as a growing medium, there is a need for several washings in fresh water and buffering by adding calcium nitrate to the material in order to remove the harmful sodium and potassium concentrations as well plays a role in availing nutrients to plants (Carlile *et al.*, 2015).

From the work of Ameho (2017), it was seen that the high CEC of cocopeat is capable of making the root zone of plants susceptible to nutrient imbalance, thereby having an impact on nutrient availability to plants.

Poulter (2014) and Schmilewski (2008) added that the additional processing of the coir increases its economic significance as well as cost.

The use of soilless substrates involves the investment of capital and due to this, it is mostly utilised in the production of crops of high value after being assured of high profitability.

It was proven from the work of Wallach *et al.* (1992) and Atland *et al.* (2010), that, as compared to soil, the soilless growing media possess lower water holding capacity, with the saturation water content being above 50% and decreasing rapidly to less than 10% for even a small increase in tension of about 20 – 40 cm of water head.

Rice husk, when used in combination with peat or coir have been discovered to perform better as compared to if it is used alone. Also, rice husk in the fresh state and the composed one have high concentrations of magnesium, therefore, if care is not taken and pH maintenance is not monitored, the problem of manganese toxicity is likely to arise.

2.4.9 Properties of Growing Media

One of the critical factors that affect the growth, development and quality of crops is the characteristics of the growing media in which it is raised (Ameho, 2017). In particular, the success of any containerised nursery crop is highly dependent on the physical and chemical characteristics of the potting medium. An ideal medium is therefore expected to be heavy enough to prevent the pot from falling off, as well as light enough to allow easy movement of water and nutrients through. That is, enough water should be retained to reduce frequent water, at the same time, enough porosity is needed to ensure effective drainage and good aeration to enhance plant growth (Massey *et al.*, 2011).

Akanbi *et al.* (2002) reiterated that in selecting any organic agricultural waste as a growing media for horticultural crops including vegetables, factors such as cost, ease of access and the physical and chemical properties need to be considered.

Due to reasons including: high porosity, fewer incidence of pest and disease infestation, less heavy nature, distinct amount of water being retained for plant use, characteristics of soilless media are usually compared to that of soil.

Although, as soon as water is added to a soilless medium, it is possible for up to 50% to be saturated in no time, this can however decrease to less than 10% even with as low a tension increase as 20 – 40 cm of water head (Atland *et al.*, 2010)

2.4.9.1 Chemical Properties of Growing Media

Plant growth and quality is seriously affected by the chemical properties of the growing media, including electrical conductivity (EC), cation exchange capacity (CEC) and pH (Cuervo *et al.*, 2012), due to this reason, they are the chemical characteristics of the media which are mostly determined (Schafer *et al.*, 2015). These properties have a direct effect on nutrient solubility and retention, therefore invariably affecting their availability for plant uptake. In the analysis of the chemical properties of a growing medium, Hwang & Jeong, (2007) stated the three major methods including: displaced media solutions, saturated media extracts and suspensions.

pH

It is the term used to refer to the power of hydrogen. It is a measurement of the acidity and alkalinity of a medium in solution form. It depicts the relationship beteween the hydrogen ions H+ and Hydroxide ions OH- in a solution, and it includes a range of number from 0 to 14 (Trejo-Téllez & Gómez-Merino, 2012)

Hartman *et al.* (2018) reported that it is very critical as it plays a big role in availing nutrients to plants, he also added that uptake of nutrients by plant roots are greatly affected by the pH of the medium. When a media is too acidic for example, nutrients like: calcium and magnesium, boron, phosphorus, nitrate-nitrogen and molybdenum are deficient, meanwhile elements like manganese and aluminum are in excess, sometimes in amounts that are harmful to some plants. Also, when a growing substrate is too alkaline in nature, mineral ions including aluminium, manganese and iron are lost and become less abundant for plant use. In such cases, nutrients like iron, zinc, molybdenum, copper and boron become insufficient for plant uptake (Mathers). With regards to this, most greenhouse crops perform best when the medium is slightly acidic, ranging from 6.3 – 6.8 in soil – based medium, 5.4 – 6.0 in the soilless medium and 5.2 – 6.3 for organic substrates (Hartman, 2018).

At optimum pH levels of substrates however, gaseous exchange through plants is facilitated, this in turn leads to ease of aeration and water infiltration and movement through the plant roots thereby ensuring healthy growth of plant (Larson, 1980).

Richard, (2006) added that pH effect on nutrient availability of the substrates is influenced by factors such as: type of fertilizer, rate of nutrient uptake by plants, pH of irrigation water, plant species, lime concentration and reaction, and container size.

Electrical Conductivity (EC)

Electrical conductivity, as described by Richard (2006), is the concentration of salt in water or other fluids resulting from flow of electrical current through them. These salts may result from the growing media components, added fertilizers or irrigation water.

Pettinelli *et al.* (1995) stated that EC represents the total dissolved salts or free ions in a medium, being contributed mostly by fertilizers. They also noted over fertilization is the major cause of abundance of soluble salt to a level where they become toxic to plants, other factors responsible for this excessive salt concentrations in media might include: inadequate watering, poor drainage, impairment of plant root function, poor drainage. This damage might occur in different form such as: leaf chlorosis, wilting, root injury and burning of leaf margins. It is usually expressed in units of deci-Siemens per meter (dS/m).

Plants raised in substrates with more than 20% composed of field soil are mostly less tolerant of higher soluble salt concentrations. These high soluble salt concentrations constitutes problems as it changes the osmotic potential of the medium, thereby making water to exit the plant roots, flowing into the substrate. This leads to poor growth of affected plants which invariably suffers from water stress and drought.

When a medium is of high EC, the amount of water supplied to the plants root is reduced, thus causing problem to the plant (Richard, 2006).

For successful production of crops, knowing the quality of irrigation water is necessary, and to know the quality of irrigation water, it is very important for the EC of the media to be confirmed (Hoffman & Shannon, 2007).

The electrical conductivity (EC) meter is used for measuring the actual amount of fertilizers mineral salt in a solution, and leachates. When the salt level is in excess, it might lead to damage or even death of succulent plant. Balliu (2017) added that high salinity can also lead to retardation of plant growth, leaf area reduction, short internodes and even necrosis in older leaves during extreme conditions. All these compounded, will seriously affect yield. To avoid problems of high salt levels, it is necessary to know: the EC of a substrate before planting and during the growing stage of the crop, the EC of the fertilizer before application so as to know the right amount and the EC of the irrigation water (Balliu, 2017; Zaccheo *et al.*, 2011).

The rate of growth and development of a crop is greatly affected by the EC of the substrate on which it is raised, if it is more than average for example, it affects growth and yield leading to a reduction in fruit yield. Substrate EC level of more than 3.5dS/m for example, as stated by Sonneveld (1985) has a negative impact on crop performance thereby reducing yield.

Recommended EC for plants (seedlings and established plants) as discovered by Lang (1996) is said to be between 1.0 – 2.0 dS/m and 2.0 – 3.0dS/m respectively. If the EC exceeds these figures, the growth of plants will be affected negatively (Acquaye, 2011).

Saeid *et al.* (2005) observed that, high EC value of 2.5 dS/m resulted in impaired growth and development, low yield and quality of soil – grown strawberries. D'Anna *et al.* (2003) on the other hand, observed better quality, increased fruit yield and higher weights of strawberry with a substrate EC of 2.5dS/m as compared with lower EC values when grown in soilless media.

In relation to cucumber, Savvas *et al.* (2013) pointed that, it is highly sensitive to salinity and an EC of not more than 2dS/m should therefore be maintained during the early stage of plant development, and as plant growth continues, there won't be any harm if it is adjusted to about 2.5 dS/m.

Table 2.1: Fertigation recommendation for soilless cucumber

Fertigation of soilless grown cucumbers		
Nutrients	**Growth Stages**	
	Establishment to Flowering	**Fruit-set - Production**
	Nutrient concentration in the irrigation water (g/m3 = ppm)	
N	150	200
P	45	50
K	220	330
Ca	100	140

Mg	40	70

N= Nitrogen; P = Phosphorus; K = Potassium; Ca= Calcium; Mg = Magnessium

Nutrient source include: Potassium nitrate (KNO_3) Magnessium sulphate ($MgSO_4$), Calcium Nitrate ($CaNO_3$) and Monoammonium phosphate (MAP).

2.4.9.2 Physical Properties of the Growth Media

The physical characteristics of a growing substrate is majorly dependent on it's ability to retain and circulate water and air. These properties include: bulk density, water-holding capacity, aeration porosity, moisture content, hydraulic conductivity and pore – size amongst others (Schafer *et al.*, 2015).

The interaction among these properties greatly influences the growth and morphology of the root systems, especially, of containerised plants. According to Awad (2010), factors such as porosity, water holding capacity and bulk density are usually affected by the distribution of water, air and solid in the substrates. For an ideal growing media, it must be ensured that necessary physical properties are in condition to enhance plant growth and development (Asaduzzaman *et al.*, 2015).

Spiers and percy (2007) noted that, the physical components of soilless media are composed of four parts including: 10-25% available water, 20-30% solids, 20-30% air spaces and 15-45% residual water.

Available water and air space are one of the important components of soilless media, these two however depend on the particle size and shape of the media (Acquaye, 2001). According to a recommendation made by Yeager (2000), the physical ideal media for raising containerized crops should have a water holding capacity of 45 to 50%, total porosity of 50 – 80%, bulk density of 0.19 – 0.70g/cm3 and an air space of 10 – 30%.

When the media is dense and has an air space of less than 10%, aeration becomes difficult, thereby limiting plant growth, although the plant can absorb more than the available water, it would rather require more energy to do this (Spiers & Percy, 2007).

Coarse particles, for example, are characterised by large pore spaces of about 0.5mm or more, this allows ease of water and air movement through the media. For substrates of medium texture, the pore spaces is about 0.1 – 0.5 mm; this also facilitates ease of water and air movement. Fine particles however, with pore spaces of about 0.1m is capable of holding water; but it is held tightly in a way that availability to plant becomes a problem. Therefore, substrate selection requires a fine mix of both ¾ coarse, 2/4 medium sized particle plus little fine particle, not more than 5% of the total substrate (Spiers & Percy, 2007).

Bulk Density

The mass per unit volume of a medium is referred to as bulk density of that medium. It is usually expressed in grams per cubic centimeters (g/cm^3), kilograms per cubic meter (kg/m^3), or by any other mass to volume units. That is, it is the dry weight of the medium occupying a particular volume as at when the substrate is moist.

Bulk density represents the rate of compaction of a growing medium, when the medium is rich in organic matter, the bulk density is low due to the associated high porosity, therefore, to increase the bulk density of this substrate, mixing with other substrates of higher bulk densities is recommended, by doing this, the plants are held more tightly, especially in containers of light weight (Ownley *et al.*, 2019; Fonteno *et al.*, 1981).

In relation to porosity, Bunt (1983) described bulk density as being inversely proportional to the pore spaces, that is: the higher the bulk density of a substrate, the lower the proportion of pore spaces.

According to Log (2008), Bulk density refers to the ratio of a substrate mass to volume for a dry sample. It is further stated that, bulk density can be calculated if the particle density of the substrate is known, by dividing the dry weight of the solid particles in the substrate by the volume of those particles); it can also be calculated from the specific weight of a dry soil as long as the porosity is known. Also, bulk density is important in converting gravimetric moisture content values to volumetric moisture content.

It has also been confirmed from the work of Fonteno *et al.* (1981) that, the bulk density of a substrate is increased by compaction and settling of the media.

In modelling variably saturated flow and transport such as HYDRUS-2D (Simunek *et al.*, 1999), bulk density serves a major purpose in preparing the numerical codes. It is also of great importance in the functioning of growth of roots and shoots of plants.

As proposed by Yeager *et al.*, (1997), the bulk density of soilless media for containerised crop production in the greenhouse should range between 0.19 to 0.7 g/cm3

Water Holding Capacity

The retentive capacity of a substrate is termed as its water holding capacity. It is the amount of moisture in the substrate after the pores (both micro and macro pores) are filled completely with water. After drainage by gravity, the percentage of a medium's pore space that still contains water is referred to as the water holding capacity of the medium. In order words, it is the total volume of water the medium is able to store for enhancement of plant's growth and development (Awad, 2010). It is the measure of the total pore spaces in a substrate.

An ideal growing substrate should possess high water – holding capacity, and at the same time adequate macropores to allow drainage of excess water, thus, preventing incidence of water logging. Dresbøll (2010) affirmed this in his statement that, both the water and aeration levels needs to be monitored so as to prevent drought incidence and excess accumulation of water respectively, especially where the media is shallow and of little quantity, as keeping both factors at equilibrum in a medium helps enhance plant growth and development. The water holding capacity of a substrate varies with its type and components. For example, if a substrate is composed of materials characterized by small pores, the substrate is likely to hold large quantities of water as compared to when it is characterised by large macropores.

To provide the plant with good physical and chemical environment, soilless growing media can be combined or used individually. Khayyat *et al.* (2007) & Michel (2013) concluded that to obtain good plant growth and development therefore, it is imperative to monitor and avail to the plant root zones adequate water and oxygen when necessary.

The most important deciding factor for healthy growth, development and performance of crops is said therefore to be the presence of water.

Moisture constants

They define definite substrate – moisture relationship, mainly the rate at which moisture is retained in the substrate.

The combination of field capacity (FC), permanent wilting point and saturation capacity is referred to as the three moisture constants.

After application of water to the surface of a medium, it moves downward, filling up the macro and micro pores, the amount of water held at this point where all the pores are filled is referred to as the field capacity, the medium is saturated and at maximum water holding capacity. The field capacity is the normal moisture capacity of the medium, as all gravitational water has drained, it is the water retained in the micropores by the medium against the force of gravity. Water at this stage is held with a pressure of 1/3 atmosphere and is readily available for use by plants.

As there is reduction in moisture content, it gets to a state when the water is held so tightly that plant roots are not able to obtain it, the plant then becomes to experience wilting, such that if it is later placed in a saturated environment, it is not able to recover in terms of turgidity and continues to wilt until water is applied to the substrate. The plant at this stage is said to be at permanent wilting point whereas the percentage of water in the soil is referred to as the wilting coefficient. The substrate at this stage is not able to supply moisture to the plant as water is held at a pressure of 15 atmosphere.

The difference between moisture at field capacity (- 0.3 bar) and permanent wilting point (- 15 bars) is referred to as the available water content of the substrate. It is the quantity of water a substrate at the wilting point requires to be able to attain field capacity. Available water is very important as it determines the amount of water the substrate can supply to the plant. It also represents the quantity of water in the plant root zone and available to the plants between irrigation and wilting.

2.5 Agronomic Parameters

2.5.1 Growth Parameters

These are the parameters usually used to estimate growth rate of plants, some of them include: plant height, number of leaves, stem girth and chlorophyll content

Plant height is a basic aspect of plants ecological set up. It contributes significant to the rate of carbon absorption of the plant specie. This is so, due to the fact that, plant height serves as one of the major factors that determines the ability of plants to compete for light as stated by Falster & Westboy (2003). It is also one of the plant characteristics that has heritability capability (Veershetty, 2004; Mohanty, 2003; Singh *et al.*, 2000)

2.5.2 Yield and Yield Parameters

Crop yield is usually affected by a lot of factors, both singly and interactively, some of which include: type of cultivar, soil, agronomic practice and weather. While some of them can be controlled, management only have little effect on others. For some years now, there has been significant increase in yield due to the awareness and proper understanding of these factors (Anderson, 2019). Some of them include: number of fruit per plant, weight of fruit per plant, mean fruit weight, fruit diameter and fruit length.

2.6 COST BENEFIT ANALYSIS (CBA)

CBA is a widely accepted tool in project appraisal (Drèze & Stern, 1987). It serves as a yardstick in estimating the value of a project, it operates by comparing the cost incurred to the benefit accrued in the achievement of a project on a monetary basis (Koopmans & Mouter, 2020).

De Rus (2021) however stated that, CBA is not all about money, neither is it about inputs or outputs, but rather about welfare. He cleared this point by explaining that money is just a common means of expressing the cost and benefit of the project. He added that CBA helps in selecting which of two or more options is the most profitable.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Description of Experimental Site

3.1.1 Experimental Site Location

The experiment took place under greenhouse condition between the periods of June 2022 to September, 2022. The greenhouse is located at Council for Scientific and Industrial Research (CSIR) - Savanna Agricultural Research Institute (SARI), close to the University for Development Studies (UDS), Nyankpala, Tolon District, Northern Region of Ghana. It is located between latitude 9.4066° N and longitude 0.9882° W, and elevation of 169m (Lawson *et al.*, 2013). The map of the experimental site is shown in figure 3.1.

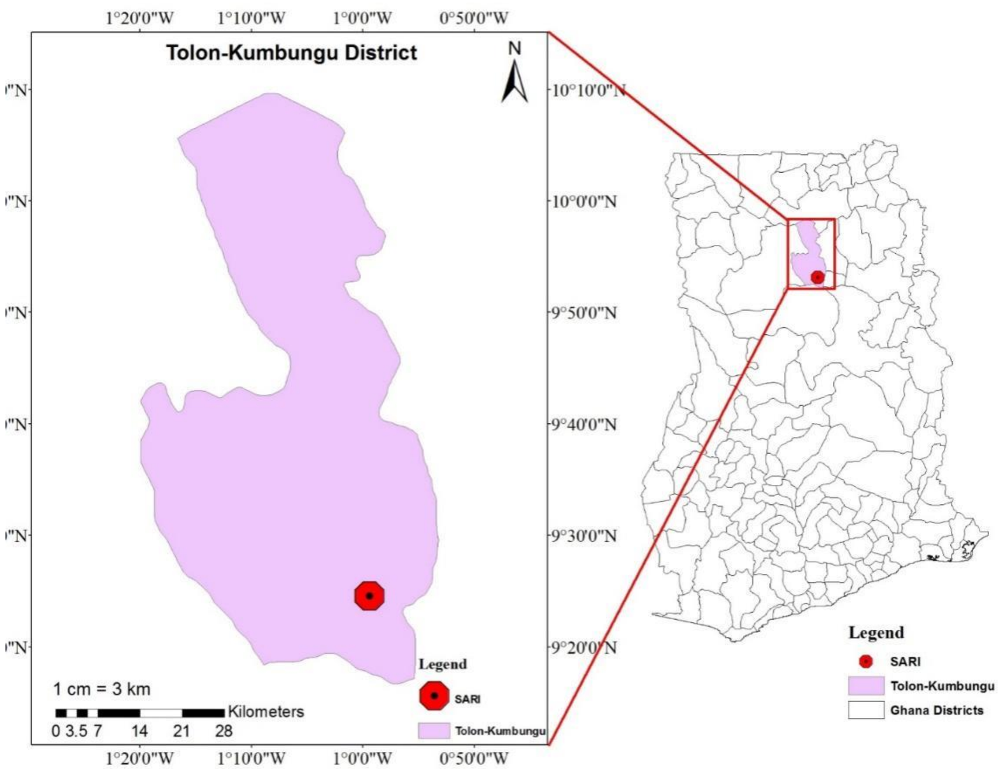

Figure 3.1: Map of the experimental site
(Field Experiment, 2022)

3.1.2 Climate

It belongs to the Guinea Savannah Agro - Ecological Zone where short drought – resistant trees are prevalent, serving as a vegetative cover. The area is characterised by a monomodal rainfall pattern. Average annual rainfall over the area is about 1,157 mm, lasting for up to 140 – 190 days. Within this period, the reference evapotranspiration (ET_o) is found to be about 2000 mm on a yearly basis, meaning that a shortfall is mostly experienced. Most of the rains are experienced between the periods of July to September, thereby making up to 60% of the annual rainfall. This is however accompanied by heavy storms which usually leaves destructive effects on crops. As in most cases, the soils are not able to withstand these damages thereby invariably resulting in large erosion and run off which serves as a major threat in agricultural fields. The dry season kicks off around November up to March. The day temperatures range between 33 and 39^{o}C, and at night, temperature drops to an average of 20 – 26^{o}C.

A drip irrigation system has been installed during the setup of the greenhouse in February 2021. During this work, water application was done through the use of the drip lines. The drip system was however programmed to supply water to the crop based on the crop water requirement which was computed using the CROPWAT 8.0 model.

3.2 Experimental design, Treatments and Replication

The experiment was a 3 x 3 factorial study laid out in Randomised Complete Block Design (RCBD) with three replications. The two sets of experimental treatments that were applied are: amount of water application and the growth media, the three water applications and three different growth media were randomised within each replication/block using random numbers. This gave each factor equal precision. A total number of nine (9) treatments were obtained, with each replicated three (3) times.

For the water application treatments, drip irrigation was utilised. The depth of irrigation application included:100 % crop water requirement (ET_c) (I1), 75 % ET_c (I2) and 50 % ET_c (I3)

The growth media included: soil(M1), soil plus charred rice husk(M2) and coco peat (M3)

Table 3.1: Treatments Description

Treatment No.	Treatment Label	Irrigation Description	Media Description	Treatment Description
	I1M1	100 % ET_c	Soil (So)	100 % ET_c, So
	I1M2	100 % ET_c	Soil + Charred rice husk (So + CRH)	100 % ET_c, So + CRH
	I1M3	100 % ET_c	Cocopeat (CP)	100 % ET_c, CP
	I2M1	75 % ET_c	So	75 % ET_c, So
	I2M2	75 % ET_c	Charred rice husk (So + CRH)	75 % ET_c, So + CRH
	I2M3	75 % ET_c	Cocopeat (CP)	75 % ET_c, CP
	I3M1	50 % ET_c	So	50 % ET_c, So
	I3M2	50 % ET_c	Charred rice husk (So + CRH)	50 % ET_c, So + CRH
	I3M3	50 % ET_c	Cocopeat (CP)	50 % ET_c, CP

(Field Experiment, 2022)

3.2.1 Treatment Preparation

To reduce the degree of bias, treatments were assigned randomly to the plants after proper labelling so as to make identification easy. After transplanting, equal water application was done for two weeks so as to enable good plant establishment, this brought the plants to field capacity after which varying of treatments started.

The layout of the experiment is as shown in Figure 3.2

Rep 1			Rep 2			Rep 3		
I1M3	I2M1	I3M2	I2M1	I3M2	I1M3	I3M2	I1M3	I2M1
I1M2	I2M3	I3M1	I2M3	I3M1	I1M2	I3M1	I1M2	I2M3
I1M1	I2M2	I3M3	I2M2	I3M3	I1M1	I3M3	I1M1	I2M2

Where:

I1 = 100% ETc	M1 = Soil (So)
I2 = 75% ETc	M2 = Soil + Charred Rice Husk (So + CRH) (75:25)
I3 = 50% ETc	M3 = Cocopeat (CP)

Figure 3.2: Layout of the experiment

(Field Experiment, 2022)

3.2.2 Treatment Sources and Preparation

Irrigation

Three levels of irrigation were used, they included: 100 % ET_c, 75 % ET_c, and 50 % ET_c

Soil

The soil used was obtained from WACWISA field, close to the meat unit of the university. The soil texture was determined to be sandy loam using the hydrometer method for determination of soil particle size determination and the USDA textural triangle (Beretta *et al.*, 2014).

Charred Rice husk

The rice husk used was obtained from a Rice mill in Nyankpala town, close to UDS. It was later carbonated using a Japan cone kiln gotten from the soil science laboratory of the University. Making use of dry woods, fire was set up on a concrete floor, after a while, it was covered with the Japan cone kiln. The kiln was then surrounded with a certain quantity of the rice husk. As the rice husk turned black, it was gradually turned over with the aid of a shovel in order to avoid complete burning of some part to ashes, and to achieve uniform burning until the desired result was obtained. The hot charred rice husk was cooled down with water after which bagging was done. It was thoroughly mixed with soil in the ratio 75:25 (So : CRH) prior to transplanting.

Cocopeat

It was obtained from Accra, buffered thoroughly with clean water before used, due to its high salinity characteristics.

3.3. Nursery Operations

Mydas variety of cucumber was sown into two seed trays. A total of 200 seeds were sown into the segments. The nursery was done in the greenhouse in order to retain moisture and allow regulation of temperature in the crop root zone. Irrigation was done daily as per the crop water requirement. Emergence of seedling started three days after planting (DAP).

3.4 Drip Irrigation System Set up

The set up included a water delivery system, main lines, sub mains, emitters, laterals, filters, valves and chemical injectors. Water was delivered through a pipe system into a polytank of size 10,000 liters, this represented the reservoir. Water supply was done under the force of gravity and also through pumping in the case of low availability. The filter helped in preventing silt and other contaminants from getting access into the system by preventing clogging of the emitters thereby ensuring delivering of clean water. The mainline with a thickness of 3.81 inches was connected to four (4) sub main lines, out of which three were used in this research. The three sub mainlines each of 1 inch diameter delivered water through the three replications. The system also consisted of a total of 216 laterals, out of which 162 were utilised in delivering water to the plants. The system also consisted of a venturi set up which was used in applying fertilizers to the plants through fertigation.

3.5 Media and Greenhouse Preparation

Prior to transplanting, the different media to be used for the research were prepared and then filled into pots, as per the total plant population. They were then arranged according to the experimental layout as shown in plate 3.1. Each pot had a depth of 20 cm with each plot having an area of 21 m^2

Plate 3.1: Arrangement of media prior to transplanting

3.6 Analysis of media

Physical and chemical tests were carried out in the soil science laboratory of the University.

3.6.1 Physical analysis of media

The physical tests carried out included Bulk density (BD), Gravimetric moisture content and Moisture constants {Saturation capacity (SC), Field Capacity (FC), Permanent Wilting Point (PWP), Available Water Capacity (AWC)}

3.6.1.1 Bulk density

Dry bulk density was determined using the core method (Blake and Hartage, 1986). In this method, weighed core rings of diameter and length 5 cm and 5 cm respectively were used to collect the media a week before planting while ensuring that the media was compressed slightly to eliminate large void spaces, it was then oven-dried at 105^0C for 48 hours to constant weight. The dry bulk density (ρ_g) was calculated thus:

$$\frac{m_1 - m_2}{\pi r^2 h} \text{..Equation 3.1}$$

where: m_1= mass of oven dried soil + core ring (g)

m_2 = mass of empty core ring (g)

h = length of core sampler (cm)

r = internal radius of core sampler (cm)

3.6.1.2 Moisture content

The different media was collected into weighed moisture cans which were immediately covered with polythene bags to prevent moisture loss. The cans were immediately transferred to the laboratory, weighed and transferred into an oven set at 105^0C for 48 hours until constant weight was attained. Gravimetric moisture content (ω) was calculated thus:

$$\frac{m_1 - m_2}{m_2 - m_3} \text{..Equation 3.2}$$

Where: m_1 = mass of moist sample + moisture can(g)

m_2 = mass of oven-dried sample + moisture can(g)

m_3 = mass of empty moisture can (g)

3.6.1.3 Moisture constants

Soil moisture constants including field capacity (FC), permanent witling point (PWP) and available water capacity (AWC) were calculated for each of the media.

To determine the field capacity, the pressure plate apparatus method was used, the different samples were collected in core rings and saturated overnight for 24 hours by covering one end of the rings with pieces of cloth and holding the cloth in place using rubber bands. These rings were then transferred into an empty bowl with the covered side placed at the base of the bowl, water was poured into the bowl so that the rings were not submerged. After 24 hours, the saturated samples were removed from the bowl, the cloth and rubber tied over one end was replaced with filter paper, this was then placed in the pressure plate extractor set to 0.33 bar to release water until field capacity was attained after 24 hours. It was then removed from the pressure plate, weighed and recorded as m1 and oven-dried at 105^0C for 24 hours to constant weight, and recorded as m2. FC was then calculated thus:

$\frac{m_1 - m_2}{m_2} \times 100$..Equation 3.3

Where: m_1 = mass of saturated soil before oven - drying (g)

m_2 = mass of oven-dried soil (g)

The permanent wilting point of the different media was calculated using the membrane apparatus. The samples were saturated for 24 hours, they were then placed in the pressure membrane apparatus where a pressure of 15 bar was applied. After extraction, samples were removed and weighed, the weight was recorded as M_1. They were then oven – dried at 105^{o}C, the weight was then recorded as M_2.

PWP = $M_1 - M_2$ ……………………………….....……………………Equation 3.4

Where:

PWP = Permanent wilting point (%)

M_1 = Mass of soil before oven drying (g)

M_2 = Mass of soil after oven drying at 105ºC (g).

AWC was thus calculated as the difference between water contents at FC and PWP.

That is;

AWC = FC – PWP…………………………………… Equation 3.5

3.6.2 Chemical analysis of media

The chemical tests included: p^H and Electrical Conductivity (EC) tests.

3.6.2.1 pH

The different media were air - dried for 24 hours after which the soil was passed through a 2 mm sieve before the test. The pH of the media was determined using the electrometric method where the 10 grams of the different media were suspended in 50 ml of distilled water. The mixture was shaken for 30 minutes and left standing for another 30 minutes. After this, the pH meter was dipped into it for the determination. This was according to the description made by Miaomiao *et al.* (2009).

3.6.2.2 Electrical conductivity (EC)

The EC of the different media was determined using the Jenway conductivity meter, by making use of the suspensions used in the p^H determination.

3.7 Irrigation Water Requirement Determination

To determine the amount of water needed by the plants during each stage of the growing season, it is necessary to carry out some estimations including:

Crop Water Requirement

Meteorological data from 1970 to 2019 were used in calculation of reference ET_o. The data that were put into consideration included: maximum temperature (Tmax), minimum temperature (Tmin), relative humidity (RH), wind speed, sunshine hours, radiation.

By employing the CROPWAT model, the ET_o was calculating on the basis of the FAO Penman – Montheith guideline, and also taking into consideration the various media to be used for production (FAO version 8.0) (Allen *et al.*, 1998).

The crop coefficient (K_c) values were also obtained from FAO irrigation and Drainage (Paper 56) on cucumber crops (Allen *et al.*, 1998), these values ranged depending on the crop stage of growth from: 0.70 to 1.05 and 0.95 for as per the initial, mid and end stage respectively.

Interpolation of the daily crop coefficient for the developmental and late season stage was made on the basis of the K_c values in combination with the period of the stages of growth. Where the period of the growth stages included: 16, 21, 25 and 15 days for the initial, development, mid and late – season stages respectively.

The crop water requirement ET_c was thus estimated as:

$ET_c = ET_o \times K_c$……………………………………………………..………………..Equation 3.6

Where:

ET_o = Reference evapotranspiration (mm)

K_c = crop coefficient

The drip irrigation system is a localized one, adjustments were thus made to convert from ET_c to ET_c crop-loc adopting the equation of Keller and Bliesner (1990), using a ground cover (Pd) of 95 %.

$Td = Ud \times [0.1 \times (Pd)^{0.5}]$ ……………………………………………………..…Equation 3.7

Where:

$Td = ET_c$ -localized

Ud = Peak ETcrop estimated conventionally

Pd = Ground cover (%)

ET_c -localized = ETcrop for localized irrigation estimated at highest demand

Net Irrigation Requirement Estimation (IR_n)

The IR_n is the quantity of water required to be received by the crop via an irrigation system, thereby ensuring complete provision of water need throughout the growing period (Doorenbos and Pruitt (1984). During this estimation, losses encountered during the process of water application are not put into consideration. In a greenhouse condition where there is no rainfall (P_e), assuming no leaching (LR), the net irrigation requirement thus became the adjusted crop water requirement (ET_c) (Savva and Frenken, 2002).

IR_n was calculated using the formula:

$IR_n = ET_c – P_e$

Since $P_e = 0$, then $IR_n = ET_c$

Gross Irrigation Requirement Estimation (IRg)

This includes the IR_n plus net water and operational losses during water application (Doorenbos and Pruitt., 1984; Savva and Frenken, 2002). That is, all water losses encountered through conveyance to application is part of IR_g.

Since drip irrigation system was utilised, application efficiency (E_a) of 95% became necessary for estimating of the IR_g. This was backed up by the statement of Coolong (2016) that the application efficiency of drip irrigation system varies between 90 and 95%.

$IR_g = IR_n / E_a$ …………………………………………………………….………… Equation 3.8

Where:

IR_g = Gross irrigation requirement (mm)

IR_n = Net irrigation requirement (mm)

E_a = Field application efficiency

3.7.1 Irrigation Scheduling

Estimations on how to schedule irrigation took place after determining the following:

- Available water content (AWC)

This has earlier discussed was estimated as the difference between field capacity moisture content and moisture content at permanent wilting point (Waller and Yitayew, 2016).

- Total available water (TAW)

This was estimated from the formula:

$TAW = (\Theta_{FC} - \Theta_{WP}) * Z_r$ ……………………………………………………Equation 3.9

Where:

Z_r = Depth of crop root zone (mm) (Doorenbos & Pruitt, 1977)

Θ_{FC} = Field capacity moisture content (%)

Θ_{WP} = Wilting point moisture content (%)

- **Readily Available Water (RAW)**

This was derived from the multiplication of the AWC by the management allowable depletion (MAD)

That is;

$RAW = AWC * MAD$ ……………………………………………………… Equation 3.10

Where:

RAW = Readily available water at all periods,

AWC = Available water content,

MAD = Management allowable depletion

To convert RAW to volumetric units, it is multiplied by the area occupied by the crop (given by interspacing * intraspacing).

Therefore:

RAW (liters) = RAW (mm) x Crop area (m^2) x 1000 liters…………………...Equation 3.11

- **Maximum Irrigation frequency:** This is gotten from the ratio of the RAW to the IR_n

That is;

$ID = \frac{RAW}{IRn}$……………………………………………………...………Equation 3.12

Where:

ID = Maximum Irrigation frequency (interval) in days

RAW = Readily available water (liters)

IRn = Net irrigation requirement (l/day)

- **Irrigation Run Time**

This was gotten from the ratio of the gross irrigation requirement to the emitter discharge

$T_a = \frac{IRg}{Q}$ ……………………………………………………………..Equation 3.13

Where:

T_a = Irrigation run time in hours

IR_g = Gross irrigation requirement (l)

Q = Emitter discharge (l/hr)

The irrigation runtime was converted from hours to minute by multiplying the result obtained by 60.

- **Water Content for Next Irrigation**

WNI = FC – (AWC) * MAD…………………………………..……………..Equation 3.14

Where:

WNI = Water content for next irrigation in liters

FC = Field capacity (%)

AWC = Available water content

MAD = Management allowable depletion

3.7.2 Distribution Uniformity of Drip Emitters

To determine the uniformity of the drip emitters, a distribution uniformity test was performed. This involved estimating the volume of water flow per unit time. Random placement of catch cans was done across the experimental site, placing eight (8) catch cans in each replication, after which the amount of water collected from each against time was noted and arranged in order of descending values. The four lowest values from each replication were averaged and average of all the values in each replication was also noted.

The distribution uniformity was thus calculated by:

$DU = \frac{Qlq}{Qa}$……………………………………………………………………….Equation 3.6

Where DU = Distribution Uniformity in %

Q_{lq} = Average rate of discharge of the lowest 1/4 of emitter discharge observations in l/hr

Q_a = Average rate of discharge of all observations (l/hr)

3.8 Greenhouse operations

3.8.1 Nursery operations

Holes in the seed tray were filled with the growing medium, seeds were then sown and watered. To retain moisture, especially at the surface, plain sheet of paper was used to cover the trays. As soon as seeds began to emerge, the pieces of paper were removed. A week after germination, a starter solution of 1g/L of NPK 20:20:20 was applied to the plants, this continued until transplanting.

3.8.2 Transplanting

After 16 days in the nursery, healthy cucumber seedlings were transplanted into the various prepared media. With each seedling having from 2 to 3 true leaves and an average height of 13 – 15 cm after careful uproot from the seed tray. This was done after irrigating the different media to field capacity. Immediately after transplanting, brief watering was done to avoid stressing the seedlings. Seedlings were transplanted 30 cm apart, leaving one seedling in a pot, giving a total of 54 plants per plot which accounted for the total plant population of 162.

3.8.3 Fertigation

The fertigation recommendation for soilless media was utilised (Table 2.1)

NPK 20:20:20 was applied to the seedling at 2 – 3 WAT, 3 - 4 WAT and 4 WAT upward at an EC of 1.2 mS/cm, 1.8 mS/cm and 2.2 mS/cm respectively. In addition, KNO_3, MAP and $MgSO_4$ were applied at an EC of 2.2 mS/cm from flowering through harvest.

3.8.4 Crop Protection (pest and disease control)

Sun – Kopper, a fungicide with bactericidal as well as fungicidal effects and having copper hydroxide as its active ingredient, was applied to the cucumber plants a week after transplanting at a rate of 35 g / 25L of water. Penncozeb 80WP with mancozeb as an active ingredient was also applied to mitigate against pest and diseases.

3.8.5 Trellising

A rope was tied slightly on the plant and gently twinned in order to avoid the stem being snapped too early and thereby reducing plant damage. Trellising is important as it provides support to the plant thereby reducing disease incidence, increasing air circulation, making other agronomic practices easier, increasing the rate of light penetration, increasing the overall fruit quality and ensuring that plants are upright.

3.8.6 Pruning

Unwanted leaves were removed on a weekly basis from 3WAT. This allowed free air circulation and nutrient transport to developing fruits and flowers

3.8.7 Harvesting

Harvesting of the fruits started 42 days after transplanting (DAT). This was done in 4 weeks based on the different replications and the corresponding weights recorded for use in estimating yield and yield components.

3.9 Collection of data

3.9.1 Temperature and Relative Humidity

Throughout the work, temperature (minimum and maximum) and relative humidity readings were taken within the greenhouse on a daily basis. This was done with the use of a thermo - hydrometer.

3.9.2 Agronomic parameters

3.9.2.1 Growth Parameters

In each row, nine plants were randomly selected, tagged and observed during the plant growing season, all data were taken on these plants in order to reduce bias. A total of 27 plants per replication, giving 81 plants in total from the entire field were tagged for the data collection.

Growth parameters including: plant height, number of leaves, leaf area, chlorophyll content and stem girth were measured on a weekly basis.

- **Plant Height:** Plant height (cm) was measured with the aid of a measure rule, the measurement was done from the media level to the apical tip of the plant.
- **Number of leaves:** this was estimated by counting physically all the true leaves on the plants
- **Stem girth:** Stem girth (mm) was measured with the use of Vernier caliper at one centimeter from the substrate level
- **Leaf area index (LAI):** this is necessary as it has a great effect on the photosynthetic ability of the plant. To estimate the LAI of a plant, the leaf area (LA) is first estimated, and the LA of cucumber plants as cited by Xiaolei & Zhifeng (2004) can be calculated by:

$$\text{Maximum length} \times \text{Maximum width} \times 0.89 \quad \ldots\ldots \text{Equation 3.7}$$

$$LAI = LA / \text{Area occupied by plant} \quad \ldots\ldots \text{Equation 3.8}$$

- **Chlorophyll Content (spad):** this was determined by making use of the chlorophyll / SPAD meter.
- **Flower count:** Counting of female flowers was done on a weekly basis, starting from 3WAT

3.9.2.2 Yield and Yield Parameters

- **Number of fruits per plant:** the average number of fruits per plant was calculated by dividing the total number of harvested fruits from the tagged plants by the total number of tagged plants
- **Weight of fruit per plant (g per plant):** All harvested fruits per treatment were weighed with an electronic weighing balance and the average was calculated.
- **Fruit Diameter (mm):** 10 fruits were randomly selected per treatment, and the diameter was measured using a pair of calipers.
- **Fruit length (cm):** the fruit length was measured from ten randomly selected fruits per treatment using a measuring tape
- **Yield (t/ha):** the weight of the fruit (kg) was multiplied by the plant population per hectare and the result divided by 1000

3.10 Cost – Benefit analysis

In order to determine which treatment gave the largest profit, the economics of each of the treatments was calculated based on the input and output.

In making decisions regarding CBA of the different growing media during this production, the factors that were considered included: irrigation water cost, procurement of the different growth media, fertilizer cost, cost of capital and total income gotten from each media.

The difference between the revenue and cost thus gives the profit

Benefit cost ratio = Benefit / Cost……………………………………………………Equation 3.7

3.11 Statistical Analysis

All relevant data were recorded, stored and managed in Microsoft excel. The collected data were arranged and organized for the suitability of statistical analysis; analysis of variance (ANOVA) was performed using Genstat software 12th edition. The significant treatment means were separated using least significance difference (LSD) at 5% probability level

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Characteristics of the growth media and irrigation water

4.1.1 Physical characteristics of the growth media

The physical properties of the different growth media indicate So had the highest bulk density of 1.41 g/cm^3, followed by So + CRH (1.03 g/cm^3) and CP had the lowest value of 0.1 g/cm^3 (Table 4.1). Gravimetric moisture content revealed CP was highest with a value of 39 % followed by So + CRH (12.6 %) with So having the lowest value of 6.5 %. The moisture content at FC varied from 12.9 % for So, followed by So + CRH at 23.87 % with CP having the highest value of 33.5 %. The moisture content at permanent wilting point also varied from 4.0 % for So, followed by So + CRH with a value of 8.7 % with CP recording the highest value of 10.8 %. Thus the available water content of the different media varied from 8.9 % to 15.17 % and 22.5 % for So, So + CRH and CP respectively.

Table 4.1: Physical properties of growth media

Growth media	Bulk density(g/cm^3)	Moisture content (%)	Field capacity (%)	Permanent wilting point (%)	Available water capacity (%)
Soil (So)	1.43	6.50	12.90	4.00	8.90
Soil + CRH (So + CRH)	1.03	12.60	23.87	8.70	15.17
Cocopeat (CP)	0.10	39.00	33.50	10.80	22.50

Amongst the important physical characteristics of a medium that influence to a great extent, the plant performance, is the bulk density and available water capacity. It is therefore necessary that the two parameters fall within the normal range (Frantz *et al.*, 2007) acceptable for optimum crop growth. The bulk density of a medium deals with its workability and porosity whereas the AWC deals with its ability to retain moisture. The bulk densities of the media fall within the range of 0.10 g/cm^3 to 1.43 g/cm^3. These variations were not unexpected (Wiberg *et al.*, 2005), and could be attributed to, amongst other factors, the differences in the particle size of the different media (Richards et al., 1986). The reduction in bulk density value of So + CRH (1.03 g/cm^3) as compared to So (1.43 g/cm^3) could be attributed to the amending effects of the CRH, which improves aeration through increase in organic matter content of the soil (Lehmann & Rondon, 2006). The value agrees with the findings of Blanco-Canqui (2017), who stated biochar reduces soil bulk density by 3 to 31 %. It also correlates with the findings of other authors including Rivenshield & Bassuk (2007), who mentioned amendment of soil with peat and wastes from food to have a reducing impact on the bulk density and possible root restriction. Both bulk densities, however, fall within appropriate values desired for adequate flow of air and moisture circulation for optimum growth of plant as pointed out by Waller and Yitayew (2016). The low bulk density of CP (0.10 g/cm^3) in this study falls within acceptable options for crops grown hydroponically, ranging from 0.1 – 0.3 g/cm^3 as demonstrated by Kämpf *et al.* (1997).

The available water capacity of the media varied from 8.9% to 22.5 %. This is not outside expectation as Awang *et al.* (2009) & Bunt (1988) explained differences in size and number of pore spaces of media to play a key role in their water holding capacities. The mixture of So + CRH has a higher available water content (15.17 %) as compared to the soil (8.9 %), attributable to the fact that CRH reduces the bulk density of soil, thereby loosening up the soil and increasing the total porosity which means more available pores for water storage and having a direct impact on the available water content of the soil (Nyle & Ray 1999). This agrees with the work of Sosu (2014) who confirmed that adding organic materials such as CRH, CP amongst others to soil leads to a significant increase in the soil water holding capacity. In an average of 90 % of cases, biochar has been found, through its organic matter incorporation into the soil, to increase moisture retention of soils by binding the soil particles together and thereby increasing the available water capacities (Chan *et al.,* 2007; Blanco & Folegatti, 2003). Sharkawi et al. (2014) reiterated this in his statement that biochar is able to increase the stability of soil structure and improve its water holding capacity. In a statement made by Peake et al. (2014), biochar is capable of increasing the available water capacity of soils by up to 22 %, this was reiterated by Nelissen *et al.* (2015) who observed biochar's effect on available water content of soils to be about 0.12 to 0.13 m^3m^{-3} increase. The CP however had the highest available water capacity value in this study, this goes in line with work of some authors where it is stated that the favorable physical characteristics of CP is associated to its high available water, slow biodegradation, low shrinkage ability and low bulk density (Evans *et al.*, 1996; Prasad, 1997).

4.1.2 Chemical characteristics of the growth media and irrigation water

The chemical properties of the growth media showed CP had the highest pH (6.48), followed by So + CRH (6.10), whereas So had the lowest pH (5.99) (Table 4.2). The highest EC was observed in CP (1878 µS/cm), followed by So + CRH (95.05 µS/cm), whereas EC was lowest in So (76.9 µS/cm). The irrigation water had a pH of 6.99 and an EC of 703 µS/cm.

Table 4.2: Chemical analysis of the growth media and irrigation water

Growth media	pH (1:2.5)	EC (µS/cm)
Soil (So)	5.99	76.9
Soil + CRH (So + CRH)	6.10	95.05
eat (CP)	6.48	1878
on water	6.99	703

(Field experiment, 2022)

In terms of importance, pH and EC are two basic properties of a medium that need to be taken into consideration before its use, as they highly affect nutrient availability and level respectively (Awang *et al.*, 2009; Motsara, 2015).

The media pH ranged 5.99 to 6.48, where So had a pH of 5.99 and So + CRH is of pH 6.1, with CP having the highest value of 6.48. As confirmed in the classification of soil reaction done by Motsara (2015), these values are classified as being moderately acidic (5.6 – 6.5). The increased pH of So + CRH (6.1) in this work as compared to soil (5.99) agrees with the findings of Wang et al. (2014) who made a point on rice husk biochar having the ability to increase the pH of soils during his work on tea garden soil where the pH increased from 3.33 to 3.63 due to rice husk biochar addition.

According to Harmann *et al.* (2011) and Sonneveld & Voogt (2009), the ideal pH for optimum growth of crops in a soilless substrate should range from 5.4 to 6.0, this point was reiterated by Adams (2002) who mentioned that the best pH for hydroponically grown crops in order to ensure optimum production is between 5.5 to 6.5, the pH of CP (6.48) used in this research falls within this range. He added that, values from 5.0 – 5.5 and 6.5 – 7.0 might not also pose a threat to most crops. The pH of CP used in this work also corresponds to that used in the work of (Evans & Konduru, 1996) where values ranged from 5.6 to 6.9.

Warncke (2007) stated that, for successful production of cucurbit species, pH range of 6.0 – 6.8 is best. Generally, a high number of nutrients are available to crops within the range of 5.5 – 6.5 (Motsara, 2015). The values of all the media were in this range, the pH can therefore be said to be acceptable and not having an impact on the results gotten.

The irrigation water had a pH of 6.99 which is classified as slightly acidic. It goes in line with the statement of Pal *et al.* (2020) who recommended a slightly acidic water pH for irrigation. The value obtained in this research remains within the desired range of 6.5–8.4 as reiterated by Schiavon & Moore (2021), and 5.2 – 6.8 as recommended by Robbins (2010), it is therefore safe for the media.

CP had the highest EC of 1878 µS/cm (1.88 dS/m) whereas So had the lowest EC of 76.9 µS/cm (0.77 dS/m). Motsara (2015) classified EC values > 4 dS/m as being saline and values < 4 dS/m as being non – saline. This indicates that the EC of the three media (So, So + CRH and CP) are non – saline. As stated by Lang (1996), for optimum seedling growth, an EC range between 1dS/m and 2 dS/m should be maintained and for the established plant, the EC should be between 2 to 3 dS/m. This is in agreement with the report of FAO, United Nations on levels on salinity where the optimum salinity value is considered as not more than 3 dS/m. If EC level is found to be higher than this, then this might be detrimental to plant growth and yield.

The EC values of all media being less than 2 dS/m indicates their suitability for cucumber growth and production (He *et al.*, 2003).

The EC of the irrigation water revealed a value of 703 µS/cm (0.703 dS/m), which is within the values desired for an irrigation water as indicated by Schiavon & Moore (2021) where it is pointed out that, an irrigation water of good quality should be < 0.75 dS/m. It also agrees with Pal *et al.* (2020) who stated that EC of irrigation water should not be up to 1 dS m^{-1}.This value also falls under the class 2 (250 – 750 µS/cm) of the salinity levels as stated by Shahid *et al.* (2018), indicating medium level of salinity and permissibility in irrigation.

4.2 Crop Water Requirement of Cucumber

In all media cases, the highest depth of irrigation water application was at 100 % ET_c ranging from 237.4 mm/dec for So and So + CRH to 237.2 mm /dec for CP; while the lowest was at 50 % ET_c ranging from 118.8 mm/dec for So and So + CRH to 118.6 mm/dec for CP.

Table 4.3: Crop Water Requirement and Irrigation Regimes of Cucumber Plant grown on So and So + CRH

Month	K_c coeff	ET_o (mm/day)	100 % ET_c (mm/day)	75 % ET_c (mm/day)	50 % ET_c (mm/day)
Jun	0.70	4.03	2.80	2.10	1.40
Jul	0.70	3.97	27.80	20.85	13.90
Jul	0.71	3.93	27.90	20.93	13.95
Jul	0.80	3.81	33.50	25.13	16.75

Aug	0.88	3.73	32.80	24.60	16.40
Aug	0.89	3.62	32.20	24.15	16.10
Aug	0.89	3.69	36.10	27.08	18.05
Sep	0.85	3.77	32.00	24.00	16.00
Sep	0.81	3.83	12.40	9.30	6.20
			237.40	178.13	118.75

(Field Experiment, 2022)

Table 4.4: Crop Water Requirement and Irrigation Regimes of Cucumber Plant grown on CP with Deficit Levels

Month	K_c coeff	ET_o mm/day	100 % ET_c mm/dec	75 % ET_c mm/dec	50 % ET_c mm/dec
Jun	0.70	4.01	2.80	2.10	1.40
Jul	0.70	3.96	27.7	20.78	13.85

Jul	0.71	3.92	27.80	20.85	13.90
Jul	0.80	3.80	33.50	25.13	16.75
Aug	0.88	3.72	32.7	24.53	16.35
Aug	0.89	3.62	32.2	24.15	16.10
Aug	0.89	3.69	36.10	27.08	18.05
Sep	0.85	3.76	32.00	24.00	16.00
Sep	0.81	3.83	12.40	9.30	6.20
			237.20	177.90	118.60

(Field Experiment, 2022)

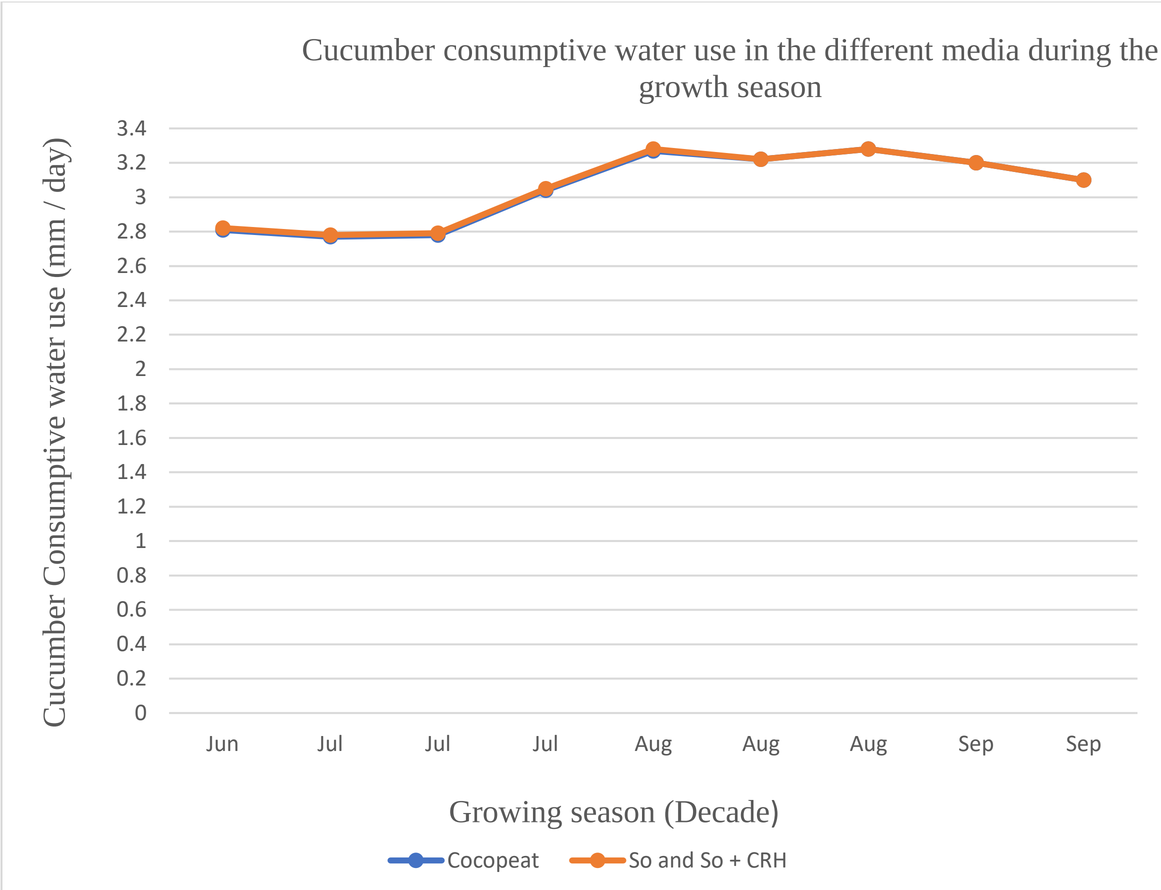

Figure 4.1: Cucumber consumptive water use (mm/day) in the different media during the growing season
(Field Experiment, 2022)

Based on the properties of the different media, irrigation became a necessary action in meeting the crop water requirement and thereby optimizing growth, with the greenhouse providing a mulch effect as well as temperature and relative humidity moderation. In relation to the different media, the crop water requirement of the cucumber was determined using the depth of water application from transplanting to harvest.

For all media, the maximum depth of net irrigation water was obtained at 100 % ET_c as expected, due to optimum moisture condition whereas the minimum was obtained at 50 % ET_c due to the stressed moisture condition.

Figure 4.1 depicts the average cucumber water uptake (mm day^{-1}) on a decadal basis in different growing substrates. At the initial stage, all CWU values were low and then increased slightly at the development stage, highest values were reached during the mid-season stage before reduction set in at end of the growth stage.

The crop water requirement values of the soil media and its mix (237.40 mm) was only slightly different from that of CP (237.2 mm); this could be attributed to the texture (sandy loam) of the soil used in this study.

The low water consumption of cucumber grown in CP as compared to So and So + CRH might be due to its high water holding capacity. This is in line with the values obtained by Mazahreh *et al.* (2015). In his work a crop water requirement value of 246 mm in Perlite + cocopeat (1:1) mixture, 254 mm in Perlite + cocopeat (2:1) mixture and 190 mm in cocopeat substrates for greenhouse cucumber was obtained. The crop water requirement value for cucumber grown in loamy soil (237.4 mm) under this study is however in contrast with the findings of Sahin *et al.* (2015) and Al-Omran & Louki (2011) where a value of 479.9 mm and 332 mm respectively were obtained for cucumber plant. This might be due to the fact that, their experiment was carried out in the open field and also depending on the texture of soil that was used.

4.4 Weather Parameters of The Crop Growing Season

Two important indices on which the performance of cucumber plants are dependent include temperature and relative humidity (Singh *et al.*, 2018). During the crop growth period; from July 2022 to September 2022, the average monthly maximum relative humidity ranged from 70.4 % to 70.5 % for the months of July and September respectively and the minimum monthly values ranged from 62 % to 54.8 % (Table 4.5). The mean maximum monthly temperature varied from 33.2 to 35.7^{o}C and the mean minimum values ranged from 28.4 to 29.8^{o}C for the months of July and September respectively.

Table 4.5: **Mean Weekly Temperature (^{o}C) and Relative Humidity (%) of the Greenhouse during the research period (DAT: 17th July, 2022)**

	Week 1		Week 2		Week 3		Week 4	
Month	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax
July	0.0	0.0	0.0	0.0	29.6	34.7	27.2	31.7
August	26.5	30.6	26.1	31.2	27.4	32.8	25.6	29.3
September	29.3	35.9	30.2	35.4	0.0	0.0	0.0	0.0
	RHmin	RHmax	RHmin	RHmax	RHmin	RHmax	RHmin	RHmax
July	0.0	0.0	0.0	0.0	54.9	66.0	69.1	74.8
August	68.0	78.8	62.0	76.6	60.7	71.7	65.8	79.4
September	54.0	67.6	55.5	73.4	0.0	0.0	0.0	0.0

Source: UT 330B Humidity / Temperature Datalogger
(Field Experiment, 2022)

Tmin = minimum temperature, Tmax = maximum temperature, RH min = minimum relative humidity, RH max = maximum relative humidity.

High productivity of a crop is highly dependent on ideal weather and climatic condition (Arthanari & Dhanapalan, 2019). This justifies the need for appropriate knowledge of the growing conditions of the environment.

The mean temperature during the cucumber growth stages ranged from 25.6^{o}C to 35.9^{o}C, whilst the average relative humidity ranged from 54 % - 79.4 %. Kumar *et al.* (2009) quoted the normal greenhouse relative humidity and air temperature to be about 80 % and 28^{o}C respectively. The obtained values fall within this range. The values are also not different from that of Hochmuth (2008) who stated that greenhouse cucumber crops do well within the temperature range of 80^{o}F – 85^{o}F (27^{o}C - 29^{o}C).

4.4 Cucumber plant growth parameters

4.4.1. Plant Height (cm) at 2, 4 and 6 WAT

At 2 and 4 WAT, plant height was not significantly ($p>0.05$) affected by the interaction of irrigation by growth media and the main effects of irrigation and growth media.

Similarly at 6 WAT, the interaction of irrigation by growth media and the main effect of growth media did not determine ($p>0.05$) plant height, but irrigation ($p<0.05$).

Irrigation regime effect: The highest cucumber height of 177.9 cm was obtained from plants irrigated at 100 % ET_c followed by 75 % ET_c (164.5 cm) whilst the lowest was observed from plants irrigated at 50 % ET_c (148.2 cm) (Figure 4.2).

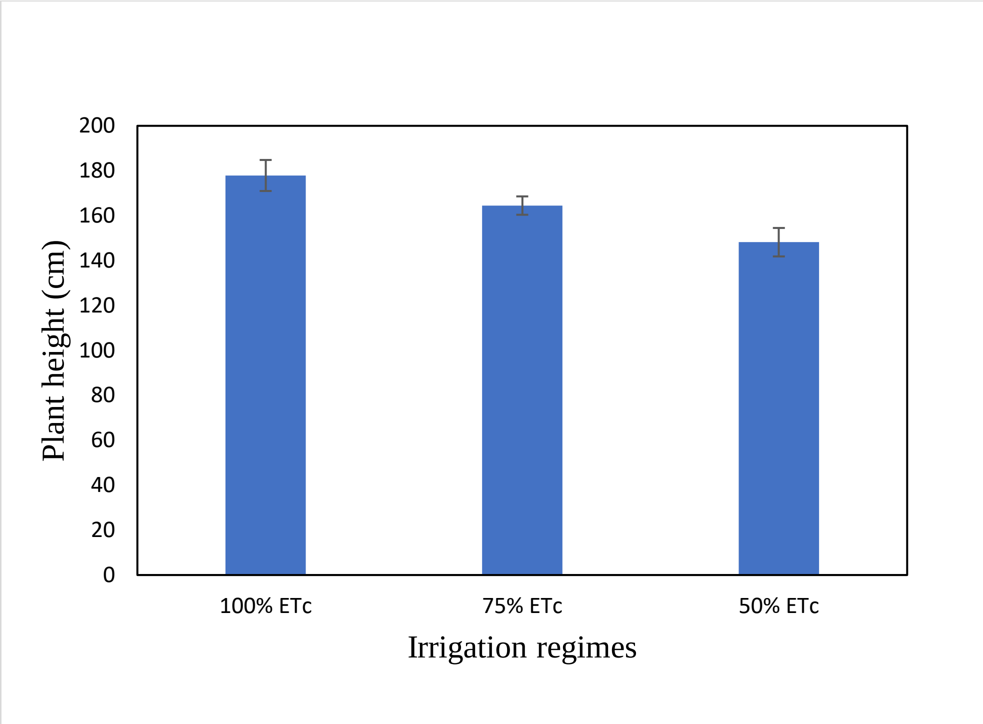

Figure 4.2: Main effects of irrigation regime on plant height at 6 WAT. Bar = Standard Error of Means (SEM)

(Field Experiment, 2022)

Plants irrigated at 100 % ET_c recorded the highest values in terms of plant height.

The increased height of plants at this irrigation regime could be attributed to higher soil moisture availability. This result goes in line with that of Ngouajio *et al.* (2007), According to him, full irrigation at 100 % ET_c supports vegetative growth of crops especially at the initial growth stage by providing a root system which is deep and extensive. Rahil & Qanadillo (2015) & Omotade (2019) also had the highest plant height at 100 % ET_c.

The low plant height of cucumber plants grown at 50 % ET_c indicated that this irrigation regime doesn't give room for maximum growth of cucumber, Rahil & Qanadillo, (2015) confirmed this statement, although they obtained highest plant height at 70 % ET_c.

Ogbodo (2012) also stated that, greater plant heights in addition to large leaf area helps in higher interception of sunlight for plants to photosynthesise.

4.4.2. Leaf Number $(\sqrt{(x + 0.5)})$ Per Plant at 2, 4 and 6 WAT

The number of leaves of cucumber plants were not significantly influenced ($p>0.05$) by the interaction between irrigation regimes by growth media and the main effects of irrigation and growth media at 2 and 4 WAT.

At 6 WAT, the interactive effects of irrigation regimes by growth media and the main effects of growth media had no significant effect ($p>0.05$) on cucumber leaf number. However, the main effects of irrigation regime did produce a significant effect ($p<0.01$).

Irrigation regime effect: Plants irrigated at 100 % ET_c (5.235) gave the highest number of leaves, followed by 75 % ET_c (5.124) whilst the lowest was recorded at 50 % ET_c (4.728) (Figure 4.3)

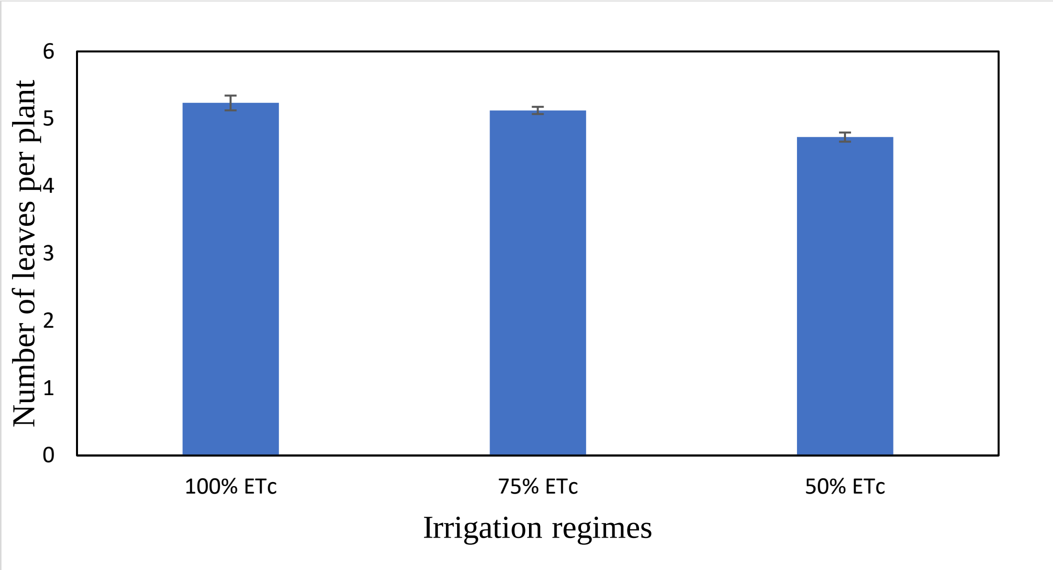

Figure 4.3: Main effects of irrigation regime on leaf number at 6 WAT. Bar = SEM

(Field Experiment, 2022)

Leaf number, one of the factors contributing greatly to plant growth, was found highest in cucumber plants irrigated at 100 % ET_c in contrast to plants at 50 % ET_c.

The leaves are a major factor in photosynthesis, high leaf number is a trigger to increased fresh weight of plants and an evidence of a good vegetative growth (Polii, 2009).

The associated increased number of leaves at 100 % ET_c could be linked to high presence of water which ultimately supports proper development of plant root thereby improving uptake of nutrients evidenced from the increased leaf number.

This result agrees with that of Sonnenberg *et al.* (2016) who pointed out that, number of leaves in cucumber plants increases with increased water application and Qu *et al.* (2022) who obtained lowest leaf number at 50 % ET_c. Same goes for Omotade (2019) where the highest number of leaves was determined by plants irrigated at 100 % ET_c and lowest at 40 % ET_c.

This is not different from what was stated by Odhiambo & Aguyoh (2022) that, stressed moisture condition (50 % ET_c) reduces leaf number of cucumber plants.

4.4.3. Chlorophyll content (Spad) at 2, 4 and 6 WAT

At 2 WAT, the interactive effect of irrigation by growth media on chlorophyll content was not significant. However, significant variations were observed in the main effects of irrigation regime ($p<0.05$), and main effects of growth media ($p<0.001$).

Irrigation regime effect: Cucumber plants at 50 % ET_c (53 spad) were highest in terms of chlorophyll content, followed by those at 75 % ET_c (44.8 spad) and those at 100 % ET_c (41.1 spad) (Figure 4.4).

Growth media effect: Cucumber plants grown in So (60 spad) produced the highest chlorophyll content followed by those grown in So + CRH (49.3 spad) and those grown in CP (29.7 spad) (Figure 4.5).

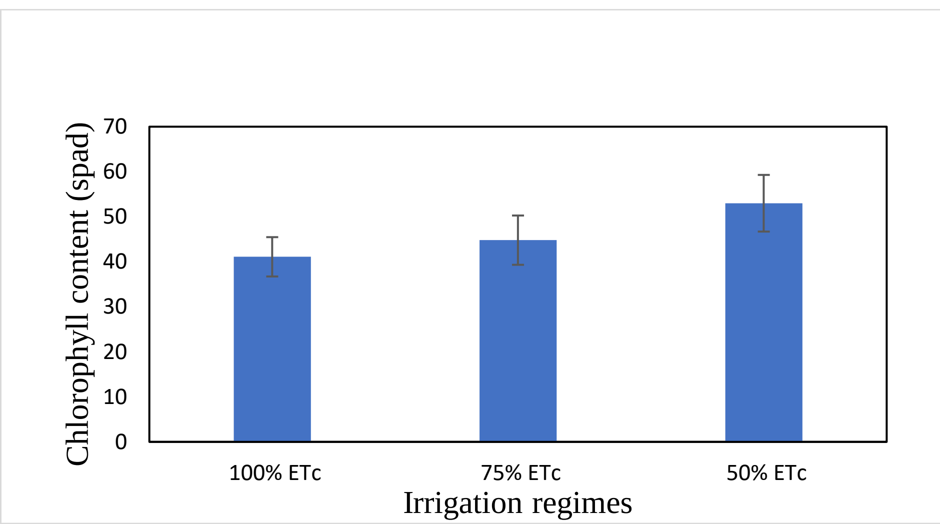

Figure 4.4: Main effects of irrigation regime on chlorophyll content at 2 WAT. Bar = SEM

(Field Experiment, 2022)

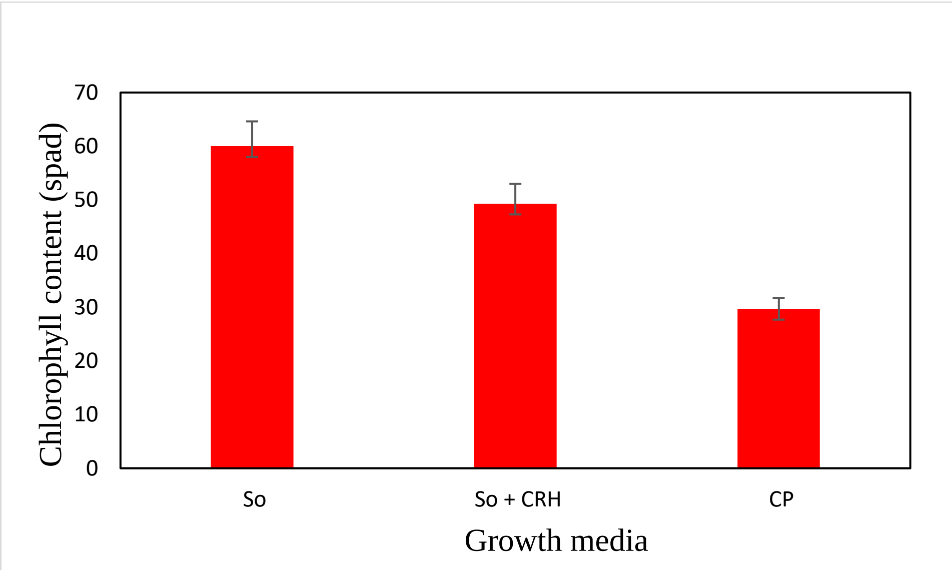

Figure 4.5: Main effects of growth media on chlorophyll content at 2 WAT. Bar = SEM

At 4 WAT, the interaction between irrigation and growth media and the main effects of irrigation regimes did not produce a significant effect on the chlorophyll content of the cucumber plant. However, the main effect of the growth media had a significant effect ($p<0.05$) on the cucumber leaf chlorophyll content.

Growth media effect: The highest chlorophyll content was observed in plants grown in So (62.1 spad), followed by those grown in So + CRH (53.9 spad) and those grown in CP (40.6 spad) recorded the lowest chlorophyll content (Figure 4.6).

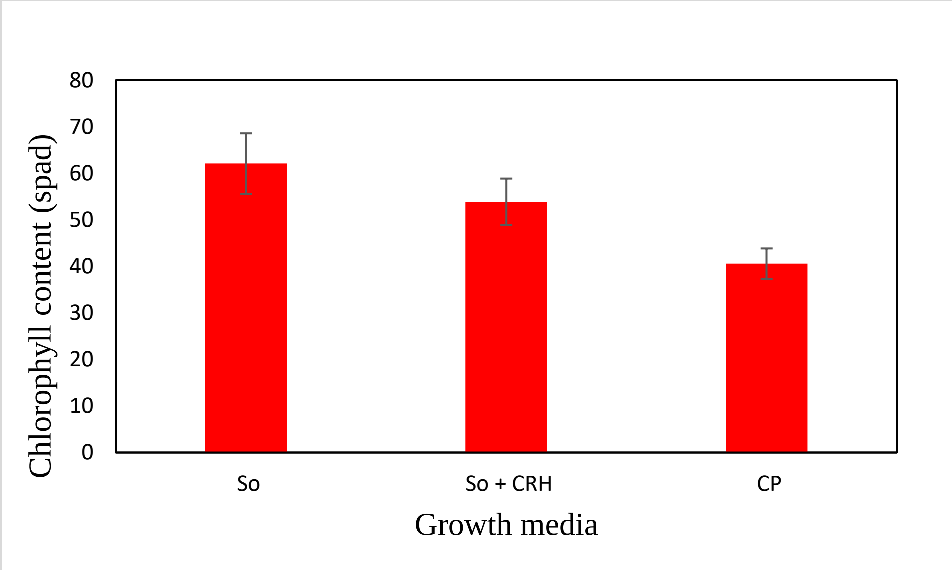

Figure 4.6: Main effects of growth media on chlorophyll content at 4 WAT. Bar = SEM

At 2 WAT, highest chlorophyll content was observed at 50 % ET_c, followed by those at 75 % ET_c whilst the lowest was recorded at 100 % Etc.

At both 2 and 4 WAT, plants grown on So had the highest chlorophyll content while those in CP had the lowest chlorophyll content. This is similar to the result of Ameho (2017) who obtained an higher chlorophyll content with cucumber plants grown on soil as compared to those grown on CP and CP plus palm fiber mixture.

The rate of absorption of N and other nutrient elements in soil and their availability might have been a factor responsible for increased chlorophyll production, evidenced from the intense green coloration of the leaves (Masoni *et al.*, 1996).

The higher chlorophyll content of So + CRH as compared to the CP in this experiment could be linked to the leaf area index. Plants grown on So + CRH had the highest leaf length and longer leaf lengths means more provision for plant chlorophyll to trap light for photosynthetic processes (Varela *et al.*, 2013).

As regards the CP in this study, the result is similar to what was obtained by Chinbuah (2018) at 4 WAT; her observation on media by size of growing bag in terms of chlorophyll content was lowest with the use of cocopeat and 5 L capacity growing bag when compared to the use of palm fiber with 5 L capacity bag.

4.4.4. Stem Girth (mm) at 2, 4 and 6 WAT

Stem girth was not significantly affected by the interactive effects of irrigation by growth media, main effects of irrigation, and main effects of growth media at 2 and 6 WAT.

At 4 WAT, the interactive effects of irrigation regime by growth media and main effects of growth media did not record a significant effect on the plant stem girth. However, highly significant difference ($p<0.001$) was observed in the main effect of the irrigation regimes

Irrigation Regimes effect: The analysis of variance shows the stem girth of cucumber plants at 100 % ET_c (7.03 mm) to be statistically higher than at 75 % ET_c (6.28 mm) and 50 % ET_c (6.17 mm) (Figure 4.7)

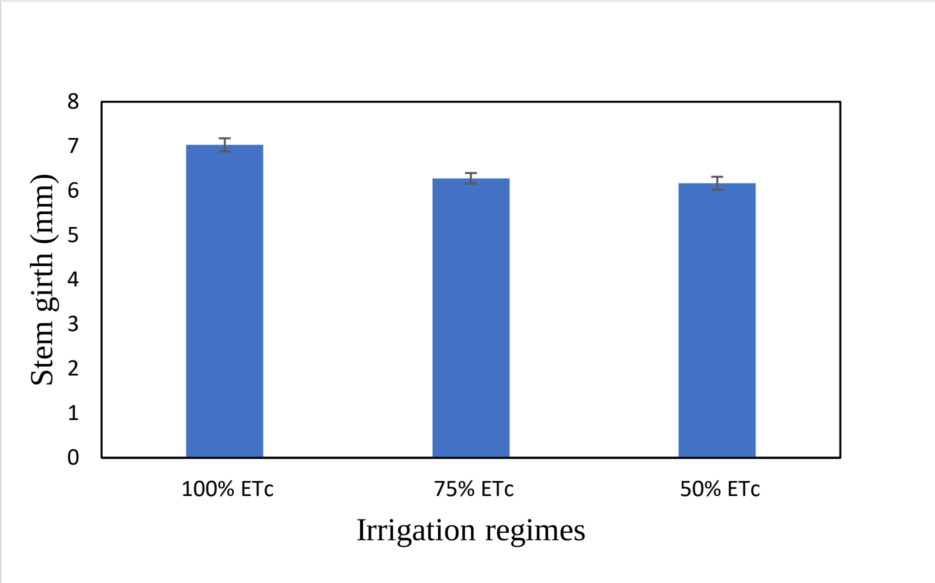

Figure 4.7: Main effects of irrigation regimes on stem girth at 4 WAT. Bar = SEM

A plant's stem girth is a major determinant of its vigour which contributes greatly to productivity. Cucumber plants at irrigation regime of 100 % ET_c had the highest stem girth whilst those grown at 50 % ET_c had the lowest. This could be attributed to the favorable moisture content at this regime.

The result however does not conform to that of Oke *et al.* (2020) who revealed highest stem girth at 75 % ET_c. The different growth media had no significant determination on the stem girth. This is in agreement with Ameho (2017) who observed no difference in the stem girth of cucumber at 6 WAT in relation to growing substrates such as cocopeat, palm fiber, charred rice husk amongst others. It also conforms to the result of Borji *et al.* (2010) who stated that stem diameter of tomato plants is not significantly determined by culture media such as date palm and cocopeat.

4.4.5. Leaf Area Index (LAI) at 2, 4 and 6 WAT

From analysis of variance result, cucumber LAI was significantly affected by the interactive effects of irrigation by growth media ($p<0.05$) and the main effects of growth media ($p<0.01$) at 2 WAT. However, the main effects of the irrigation regimes had no significant effect on the LAI.

Interactive effect: The LAI was highest for cucumber plants grown on So + CRH at 100 % ET_c (0.0567) followed by plants grown on So + CRH at 50 % ET_c **(**0.0565), followed by So at 50 % ET_c and CP at 75 % ET_c (0.0533), followed by So at 100 and 75 % ET_c and So + CRH at 75 % ET_c (0.05). the lowest was recorded in cucumber plants grown on CP at 100 and 50 % ET_c (0.04).

Table 4.6: Irrigation regimes and growth media interactive effects on LAI at 2 WAT

IRRIGATION	GROWTH MEDIA		
REGIMES	So	So + CRH	CP
100% ET_c	0.05	0.0567	0.04
75% ET_c	0.05	0.05	0.0533
50% ET_c	0.0533	0.0565	0.04
P value	> 0.01		
Lsd (5 %)	0.00948		

(Field Experiment, 2022)

At 4 WAT, the interactive effects of irrigation regime by growth media and main effects of irrigation regimes did not produce a significant effect (p>0.05) on the LAI but the main effects of the growth media (p<0.05).

Growth media effect: The highest LAI was deduced from plants grown in So + CRH (0.061) followed by those in So (0.054) and CP (0.052) (Figure 4.8)

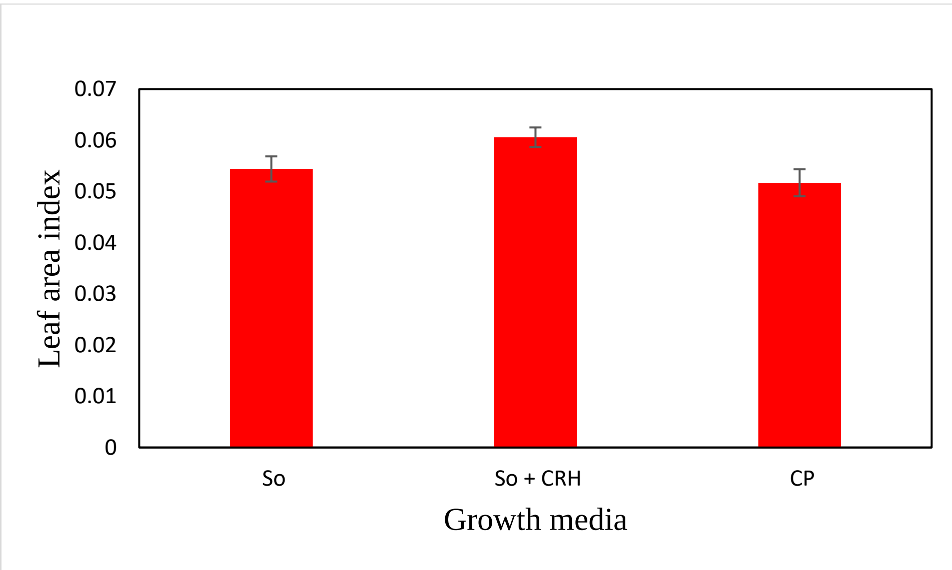

Figure 4.8: Main effects of growth media on LAI at 4 WAT. Bar = SEM

(Field Experiment, 2022)

The interaction between irrigation regime and growth media on LAI at 6 WAT resulted in no significant difference (p>0.05). There was however, significant variations in the main effects of irrigation regimes (p<0.01) and the main effect of growth media (p<0.05).

Irrigation regime effect: Cucumber plants irrigated at 100 % ETc recorded the highest LAI of 0.063 followed by 75 % ETc (0.058) and 50 % ETc (0.052) (Figure 4.9).

Growth media effect: LAI was highest for plants grown on So + CRH (0.063) followed by So (0.058) and CP (0.053) (Figure 4.10).

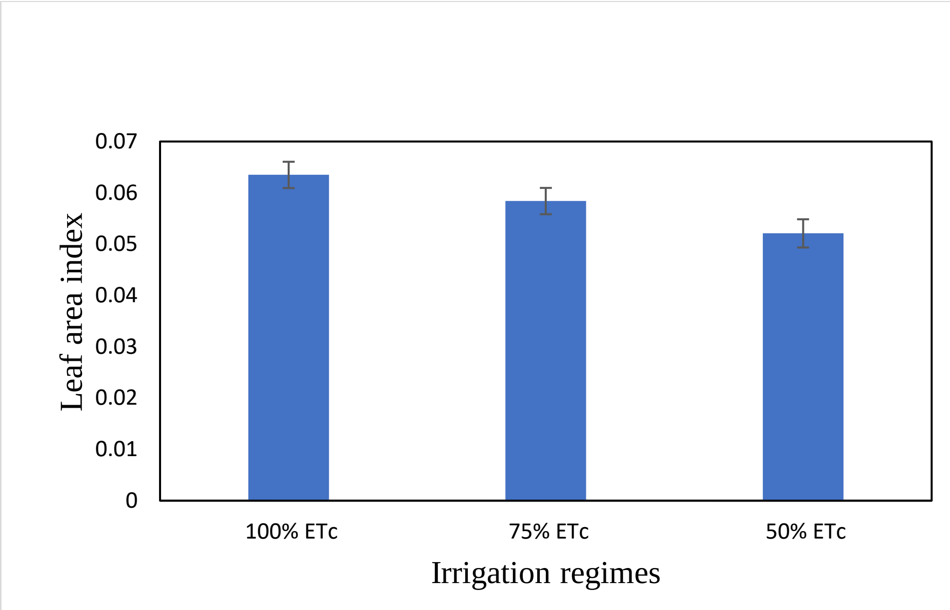

Figure 4.9: Main effects of irrigation regimes on LAI at 6 WAT. Bar = SEM

(Field Experiment, 2022)

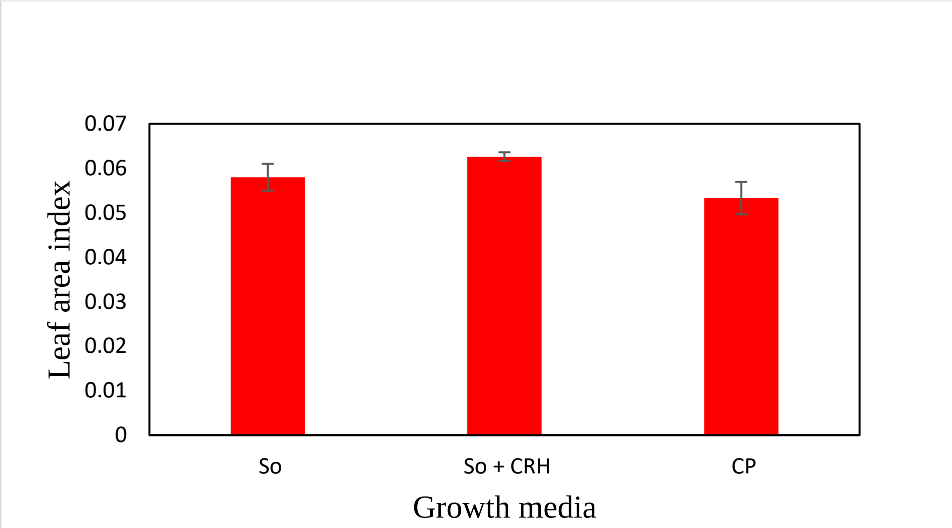

Figure 4.10: Main effects of growth media on LAI at 6 WAT. Bar = SEM

(Field Experiment, 2022)

The highest leaf area index value was obtained from cucumber plants grown on So + CRH at 100% ET_c at 2 WAT.

The different irrigation regimes didn't produce a significant effect on cucumber LAI except at 6 WAT where it was highest at 100 % ET_c. This correlates with the findings of Gibberson *et al.* (2016), from his work, stem diameter, length, leaf number and leaf area are decreased when moisture is in deficit. Leaf area reduction at this irrigation regime (50 %) could also be traced to the reduced chlorophyll content at these regimes, coupled with decreased uptake of CO_2 which reduces photosynthesis rates in plants (Gibberson *et al.*, 2016). The result is also in corroboration with other authors where it is said that, drought situation in most plants results in reduced leaf area, retardation of plant moisture status and transpiration and reduction in production of dry matter.

Meanwhile cucumber plants grown on So + CRH had the highest LAI whilst those grown on CP had the lowest.

Leaf area index is a function of the leaf area which is a combination of leaf length and width. Leaf area, as defined by Hussein (2020) is a factor that has a very significant effect on the rate at which photosynthesis occur in plants.

The result from this research goes in line with that of Rahayu *et al.* (2022) who obtained the largest leaf width from soils treated with rice husk biochar at 15 $tonsha^{-1}$ with this being significantly different from the other treatments, he then concluded that biochar availability in plants can increase the width, thereby having a positive effect on production (Akmal & Simanjuntak, 2019)**.**

The result does not however agree with that of Nikrazm *et al.* (2011) who stated that, cocopeat was better than inorganic substrates as regards lily flower leaf area.

Invariably, large leaf width means more nutrients capture as long as the needed fertilizer is applied to the plants, fulfilment of the plants demands in terms of nutrients helps optimize their growth and development (Aditiameri, 2016). The importance of high leaf area is further reiterated by Sari *et al.* (2016) who confirmed that high leaf area enhances obtainment of sunlight and fixation of CO_2 thereby speeding up photosynthesis process in plants.

The lowest LAI in terms of growth media was observed with cucumber plants grown on CP.

This agrees with the work of Sosu (2014) who found an increase with soil mixed with charred rice husk as compared to soil and soilless media as regards leaf area, plant stem girth, plant height, root dry weight and total dry weight. This result is, however, in contrast with Nikrazm *et al.* (2011) whose work showed better cocopeat performance as compared to inorganic media with respect to lily flower leaf area.

Ogbodo (2012) had reiterated the importance of large leaf area as it helps plants in fast interception of sunlight thereby aiding photosynthesis as compared to plants with smaller leaf areas.

4.4.6. Flower Count $(\sqrt{(x + 0.5)})$ Per Plant at 3, 4, 5 and 6 WAT

Significant differences were noted for the interactive effect of irrigation regimes by growth media ($p<0.01$), the main effect of irrigation regimes ($P<0.05$) and the main effect of growth media ($p<0.01$) on flower count on 3 WAT.

Interactive effect: Cucumber flower count decreased in the order CP at 75 % ET_c > So + CRH at 100 % ET_c and 75 % ET_c > CP at 100 % ET_c and 50 % ET_c, So at 100 % ET_c > So at 50 % ET_c > So + CRH 50 % ET_c > So at 75 % ET_c (3.14, 3.03, 2.97, 2.86, 2.74, 2.68,2.61) (Table 4.7).

Table 4.7: Interactive effects of irrigation regimes and growth media on flower count at 3 WAT

IRRIGATION	GROWTH MEDIA		
	So	So + CRH	CP
100 % ET_c	2.86	3.03	2.86
75 % ET_c	2.61	2.97	3.14
50 % ET_c	2.74	2.68	2.86

P value	<0.01
LSD (5 %)	0.1943

(Field Experiment, 2022)

The interactive effects of irrigation regimes by growth media had no significant effect on flower count at 4 WAT. Significant differences were however observed in the main effect of irrigation regimes ($P<0.05$) and the main effect of growth media ($p<0.01$).

Irrigation regimes effect: Flower count was highest at 100 % ET_c (3.34), followed by 75 % ET_c (3.33) and 50 % ET_c (3.01) (Figure 4.11).

Growth media effect: The highest flower count was recorded by plants grown in CP (3.48), whilst the lowest was recorded by So (3.08) (Figure 4.12).

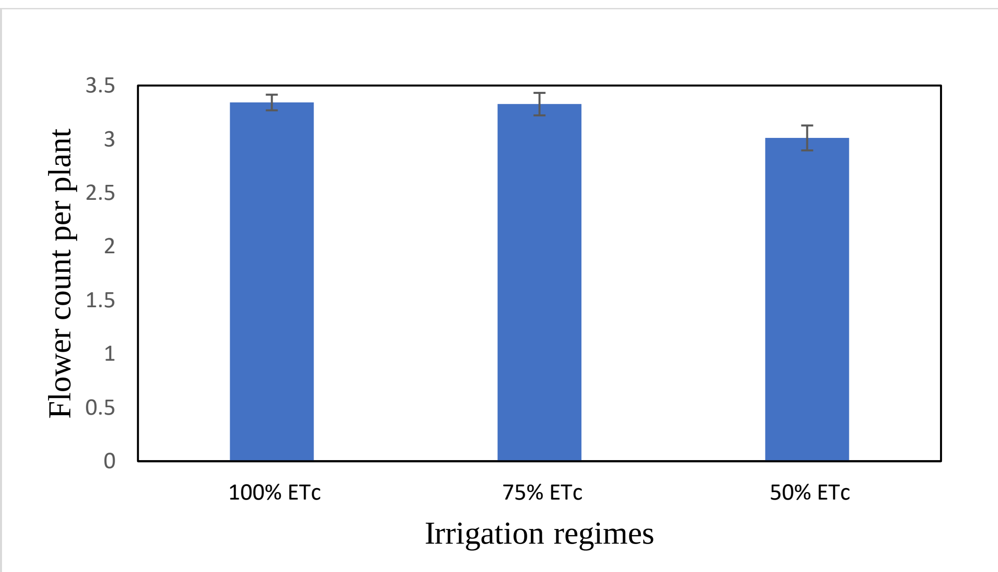

Figure 4.11: Main effects of irrigation regimes on flower count at 4 WAT. Bar = SEM

(Field Experiment, 2022)

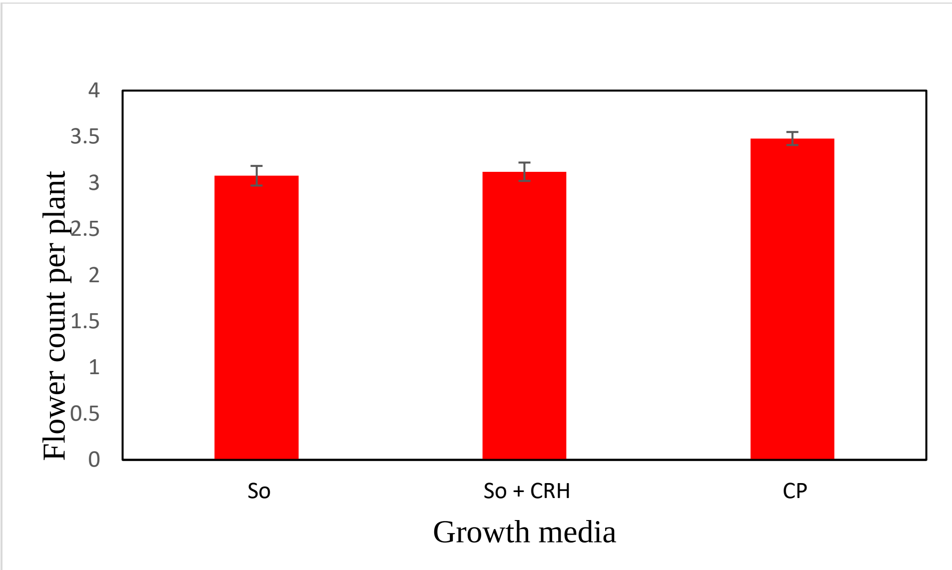

Figure 4.12: Main effects of growth media on flower count at 4 WAT. Bar = SEM

(Field Experiment, 2022)

At 6 WAT, the interactive effects of irrigation regimes by growth media and the main effects of growth media and had no significant effect on flower count. It was significantly affected by the main effects of irrigation regimes ($p<0.05$).

Irrigation regime effect: Cucumber plants irrigated at 100 % ET_c (2.87) accounted for the highest flower count followed by 75 % ET_c (2.69) and 50 % ET_c (2.38) (Figure 4.13).

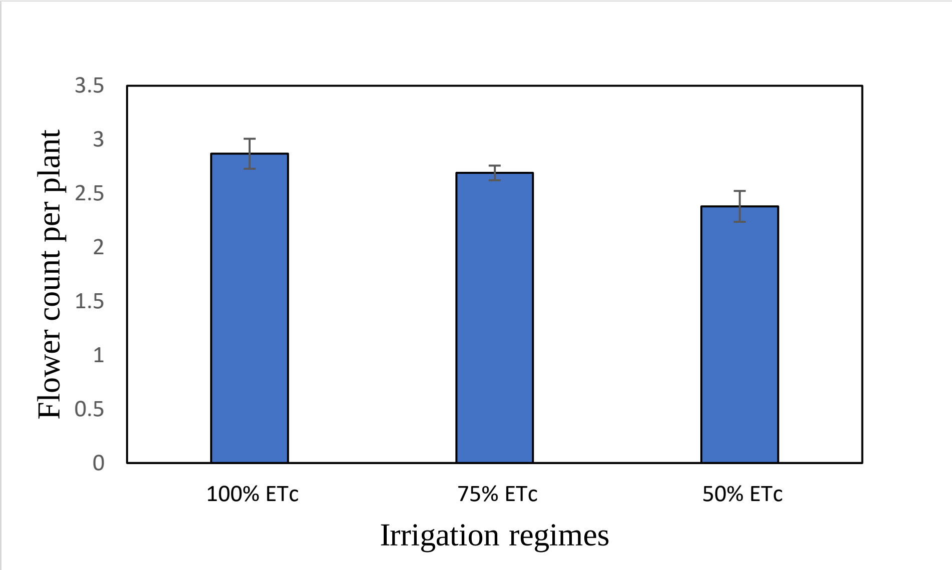

Figure 4.13: Main effects of irrigation regimes on flower count at 6 WAT. Bar = SEM *(Field Experiment, 2022)*

Flowering stage has proven to be the most vulnerable stage among the plant growth stages and reduced provision of water is one of the main factors responsible for flower abortion (Jaimez *et al.*, 2000).

The number of flowers were significantly affected by irrigation as highest flower count was obtained at 100 % ET_c whereas the lowest was recorded at 50 % ET_c.

As deficit irrigation increased, number of flowers reduced. This is not unexpected as Hott, *et al.* (2018) had confirmed that high moisture presence promotes production of flowers in crops. This result conforms to that of Silva *et al.* (2021) who observed that irrigation regimes ranging from 100 – 115 % gave more flowers as compared to 50 % ET_c. and Ragab *et al.* (2019) where flower number was reduced at an irrigation regime of 55 %.

Ganeva *et al.* (2019), when comparing the control of 100% ET_c to 50 % ET_c, also pointed out a 25 % negative effect on flower number at a stressed level of 50 % ET_c. This result is also in conformity with that of Ragab *et al.* (2019) who found a significant reduction in flower number at 55 % ET_c as compared to the full irrigation regime of 100 % ET_c.

The highest flower count was associated with plants grown on CP whereas the lowest was associated with the So grown plants.

4.4.7. Flower Abortion $(\sqrt{(x + 0.5)})$ Per Plant at 4, 5 and 6 WAT

At 4 WAT, the interactive effects of irrigation regimes by growth media and main effect of irrigation regimes did not significantly alter flower abortion. Abortion of flowers was however significantly determined by the main effects of the growth media

Growth media effects: Statistical analysis of variance result depicted highest flower abortion as being recorded in cucumber plants grown on So + CRH (1.42) followed by So (1.12) with CP (0.95) recording the lowest (Figure 4.14).

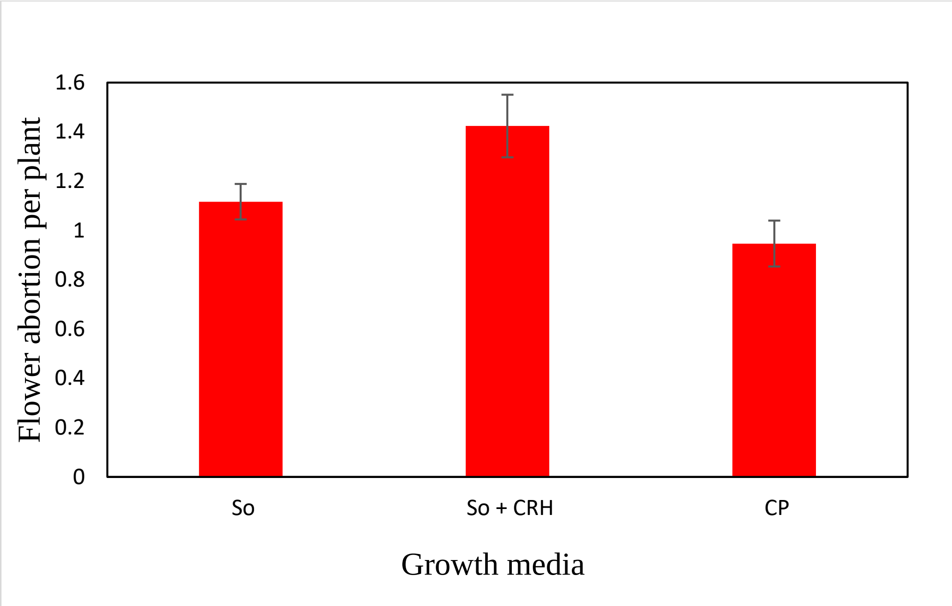

Figure 4.14: Main effects of growth media on flower abortion at 4 WAT. Bar = SEM
(Field Experiment, 2022)

At 5 WAT, Flower abortion was significantly affected by the interactive effects of irrigation regimes and growth media ($p<0.05$) and the main effects of growth media ($p<0.001$). The effects of the different irrigation regimes produced no significant effect on the flower abortion.

Interactive effects: Results obtained revealed that flower abortion in the cucumber plant occurred in the order So + CRH at 75 % ET_c (3.29)> So + CRH at 75 % ET_c (3.24)> CP at 75 % ET_c (3.24)> So + CRH at 50 % ET_c (3.07) > CP at 50 % ET_c (3.02) > So at 50 % ET_c (2.91) > So at 100 % ET_c (2.86) > CP at 100 % ET_c (2.85) > So at 75 % ET_c (2.68).

Table 4.8: Interactive effects of irrigation regimes and growth media on flower abortion at 5 WAT

IRRIGATION	GROWTH MEDIA		
	So	So + CRH	CP
100 % ET_c	2.86	3.24	2.85
75 % ET_c	2.68	3.29	3.24
50 % ET_c	2.91	3.07	3.02
P value	<0.05		
LSD (5%)	0.2851		

(Field Experiment, 2022)

Highest flower abortion was associated with cucumber plants grown on So + CRH at 75 % ET_c

When this irrigation regime is compared to 100 % ET_c, the result agrees with the statement of Kaya *et al.* (2005) that shortage of water in plants could result in flower and fruit loss in cucumber cultivation. As compared to 50 % ET_c however, high flower abortion at this irrigation regime is in contrast with other researchers who quoted increase in deficit irrigation to increase rate of flower abortion (Ganeva *et al.*, 2019). Steduto *et al.* (2012) affirmed the importance of sufficient irrigation, not in excess though, to reduce susceptibility of flower loss and fruit dropping.

Mends (2019) mentioned that, flower abortion is seriously affected by genotype and environmental conditions. During the period of the research, the temperature and relative relative humidity remained within the normal range required for cucumber productivity, ranging from 29.3 – 35.9^{o}C and 54 % - 73.4 % respectively. The high rate of abortion in plants grown on So + CRH could however be linked to disease infestation observed in the plants, although, appropriate measures were taken against this in order not to affect the yield eventually.

4.5 Cucumber Yield

4.5.1 Average fruit number $(\sqrt{(x + 0.5)})$ per plant

The number of fruit obtained from each cucumber plant was not significantly determined by the interactive effects of irrigation regimes and growth media and the main effects of growth media but by the main effects of irrigation regime ($p<0.001$)

Irrigation regime effect: the highest fruit count per plant was recorded for plants irrigated at 100 % ET_c (3.95) followed by 75 % ET_c (3.35) while the lowest was recorded at 50 % ET_c (2.5) (Figure 4.18).

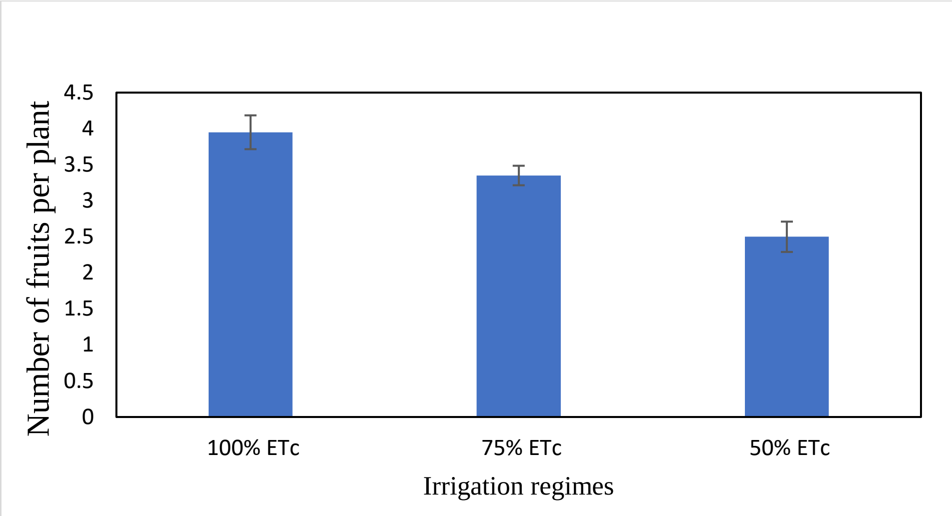

Figure 4.18: Main effects of irrigation regimes on fruit count. Bar = SEM

(Field Experiment, 2022)

The average fruit count was highest at 100 % ET_c and lowest at 50 % ET_c. This is attributable to the favorable media moisture at this regime.

This result conforms to that of Sahin *et al.* (2015) & Adeogun (2017) who attributed increased fresh fruit to increased irrigation amount.

4.5.2 Average weight (g) of fruit per plant

Cucumber weight was not altered significantly ($p>0.05$) by the interaction of irrigation regime by growth media and main effects of growth media; the main effects of irrigation however had a significant influence ($p<0.05$)

Irrigation regime effect: The different irrigation regimes significantly determined the average weight of cucumber fruit with 100 % ET_c (342.4g) recording the heaviest fruits followed by 75 % ET_c (295.5g) and 50 % ET_c (281.1g)

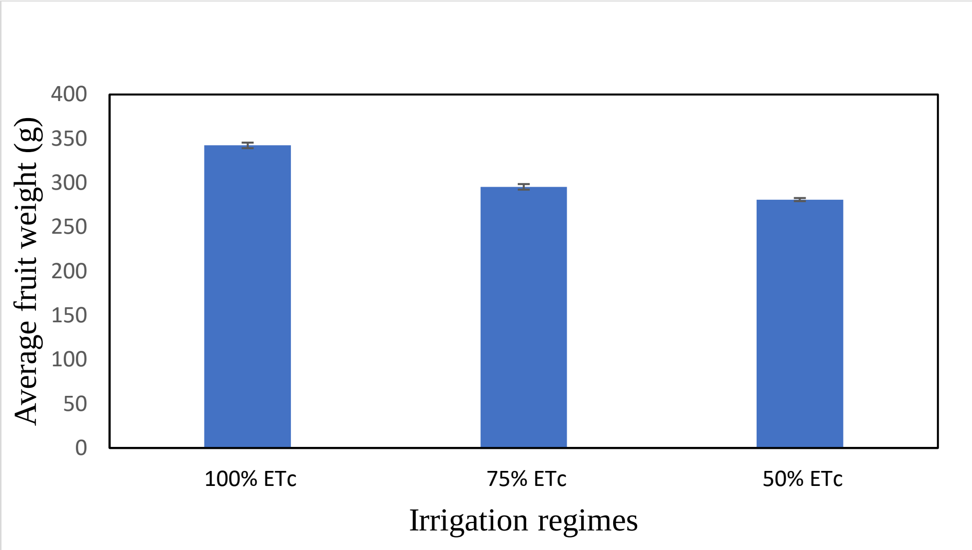

Figure 4.19: Main effects of irrigation regimes on fruit weight. Bar = SEM

(Field Experiment, 2022)

Weight of the plant is a very important parameter as it represents a major portion of the yield. Cucumber fruits irrigated at 100 % ET_c were the heaviest followed by 75 % ET_c and 50 % ET_c. This result conforms with the research of Mamun-Hossain *et al.* (2018) & Sahin *et al.* (2015) who had highest fruit weight at 100 % ET_c. This contradicts other researchers including Omotade (2019) who had highest cucumber fruit weight at 80 % ET_c

4.5.3 Average yield (t/ha)

Yield (t/ha) was not significantly affected by the interaction of irrigation regimes by growth media and main effects of growth media but by the main effects of irrigation regimes.

Irrigation regimes effect: Highest yield was obtained from cucumber plants irrigated at 100 % ET_c (116.3 t/ha) followed by 75 % ET_c (70.6 t/ha) and 50 % ET_c (37.8 t/ha) (Figure 4.20).

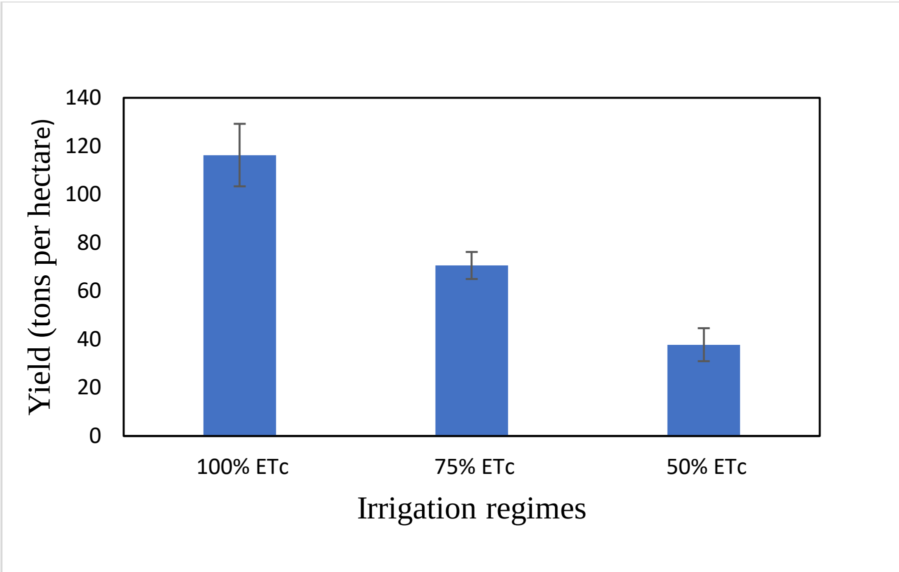

Figure 4.20: Main effects of irrigation regimes on yield. Bar = SEM

(Field Experiment, 2022)

The effect of irrigation amount on cucumber fruit yield cannot be over emphasized (Hashem *et al.*, 2011; Sahin *et al.*, 2015; Zhang *et al.*, 2019). As the quantity of irrigation decreased, cucumber yield reduced, this could be linked to the high moisture availability as cucumber plants are known to be water – loving, most especially at the flowering and fruiting stage. This could also be associated with the increased plant height at this irrigation regime as compared to 75 % and 50 % ET_c as tall plants are able to intercept more light for optimum photosynthesis to take place.

This result agrees with other researchers who also found highly appreciable yield with 100 % ET_c and thus, reported increased yield of cucumber to have a linear relationship with increasing water application (Adeogun, 2017; Al-Omran & Louki, 2011; Ayas & Demirtas, 2009; Odhiambo & Aguyoh, 2022; Sahin et al., 2015b)

The result was however in contrast with some other researchers such as Rahil & Qanadillo (2015) where the highest fruit yield was determined by plant irrigated at 70 % ET_c followed by those at full irrigation of 100 % ET_c, Omotade (2019) who determined highest fruit yield at 80 % ET_c and Mamun-Hossain *et al.* (2018)where highest yield was obtained at 85 % ET_c.

Irrespective of the irrigation regime that gave the highest fruit yield, lowest cucumber fruit yields is mostly associated with irrigation at 50 % ET_c as confirmed by this work and other researches (Adeogun, 2017; Omotade, 2019; Rahil & Qanadillo, 2015; Sahin *et al.*, 2015)

4.6 Yield attributes of cucumber

4.6.1 Average fruit length (cm)

Cucumber fruit length was significantly depicted by the interactive effects of irrigation regime by growth media and main effects of irrigation regimes ($p<0.01$) but not by the main effects of the growth media.

Interactive effects: Longest fruit was obtained from cucumber plants in the decreasing order of CP at 100 % ET_c (25 cm)> So at 100 % ET_c (22.67 cm)>So at 75 % ET_c (22.42 cm)>So + CRH at 75 % ET_c (21 cm)> So + CRH at 50 % ET_c (20.67 cm)> So + CRH at 100 % ET_c (20.5 cm)> CP at 75 % ET_c and So at 50 % ET_c (19.17 cm)> CP at 50 % ET_c (18.67 cm)

Table 4.9: Interactive effects of irrigation regimes and growth media on fruit length

IRRIGATION	GROWTH MEDIA		
REGIMES	So	So + CRH	CP
100% ET_c	22.67	20.5	25
75% ET_c	22.42	21	19.17

50% ET_c	19.17	20.67	18.67
P value	<0.05		
LSD (5%)	3.180		

(Field Experiment, 2022)

Longest cucumber fruits were achieved on CP grown plants irrigated at 100 % E ET_c.

This is in conformity with that of other researchers including Odhiambo & Aguyoh (2022) & Sahin *et al.* (2015) who also obtained the highest cucumber length from plants irrigated at 100 % ET_c.

This result is however not in agreement with researchers such as Omotade (2019) where the longest fruits were observed on cucumber plants irrigated at 80% ET_c and Mamun-Hossain *et al.* (2018) who recorded highest fruit length at 65 % ET_c.

Plants grown in CP recorded the highest average length, this could be attributed to their highly developed root systems which enables maximum exploration of the media thereby leading to higher absorption of water and nutrients, thus making them perform optimally as regards fruit length. This result is in line with Ameho (2017) who reported highest fruit length in CP, palm fibre and CP plus palm fibre.

4.6 Correlation analysis

Plant height correlated highly and positively with stem girth and flower count. Leaf area index correlated highly and positively with the flower count and the total fruit count correlated highly and positively with the fruit yield. The coefficients of correlation were; r = 0.65, 0.62, 0.63 and 0.85 respectively (Table 4.10).

Table 0.1. Correlation Analysis of Fruit Yield, Growth and Yield components

	PH	NLV	STG	CLC	LAI	FLW	ABT	FRT	YLD
PH	1								
NLV	0.5202	1							
STG	0.6458**	0.1436	1						
CLC	0.2332	0.209	0.2725	1					
LAI	0.5304	0.4726	0.0635	0.1508	1				
FLW	0.6152**	0.4425	0.2338	0.2945	0.6293**	1			
ABT	0.2144	-0.2889	0.5361	0.1741	-0.2578	-0.1558	1		
FRT	0.4692	0.4057	0.2921	0.0031	0.3543	0.3532	0.1621	1	
YLD	0.4487	0.5259	0.2094	-0.0859	0.4231	0.316	0.0933	0.8474**	1

PH = Plant height; NLV = Number of leaves; STG = Stem girth; CLC = Chlorophyll content; FLW = Flower count; ABT = Flower abortion; FRT = Fruit count; YLD = Fruit yield ; ** = Highly correlated

4.7 Benefit cost analysis

The total cost incurred in obtaining the different media and the benefit accrued is as depicted in Table 4.11. CP (GH₵ 584) had the highest cost incurred followed by So + CRH (GH₵464) and So (GH₵434). Benefit accrued was in the order CP> So> So + CRH at GH₵702, GH₵551.9 and GH₵503.8 respectively. The benefit cost ratio thus ranged from 1.10 for So + CRH to 1.20 for CP and 1.27 for So.

Table 4.11: Cost - Benefit Analysis (CBA) of the growth media

	Growth media Quantity			Growth media Cost (GH₵)		
	So	So + CRH	CP	So	So + CRH	CP
se	260kg	260kg	120kg	-	-	150
ort	Open field to greenhouse	Open field to greenhouse	Accra to greenhouse	50	50	100
ıg	-	30kg	-	-	20	-
	65 pieces	65 pieces	65 pieces	35	35	35
Pots	54 pieces	54 pieces	54 pieces	54	54	54
Water	305 litres	305 litres	300 litres	250	250	200
Fertilizer	1kg	1kg	1kg	30	30	30
Fungicide	50g	50g	50g	15	15	15

Total cost incurred	434	454	584
Benefit accrued	551.9	503.8	702
Benefit cost ratio (BCR)	1.27	1.10	1.20

In order to assess the profitability of the growth media utilised in this study, the benefit cost ratio was determined (Price Gittinger, 1984). Result for the CBA revealed So had the highest benefit cost ratio (BCR), followed by CP while So + CRH had the lowest.

The highest profitability associated with So was due to the low production cost.

CP had the highest benefit as it produced the highest number of fruit, although the BCR was lower than So. The low BCR as compared to that of soil is due to high initial cost as compared to the other media.

Although, the cost incurred in availing So + CRH for the research is a bit higher than that of So due to the labour involved and cost of fuel for the process of charring, it however accounted for the lowest profit which lead to low BCR, this might be due to the high rate of flower abortion associated with it in this research. The flower abortion had an effect on the total number of fruits harvested as part of the fruits that could have been harvested were lost through flower dropping. The low cost incurred in getting the rice husk conforms to the findings of Acuna *et al.* (2004) that the production cost of soilless media can be reduced if local materials are utilised.

This result agrees with Ameho (2017) who obtained lowest profit from CP and CRH grown cucumber.

All media however had BCR greater than one, this means making use of any of the media is profitable and this agrees to Price Gittinger.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Results from statistical analysis revealed that, plant height (188.2 cm), number of leaves (5.42), stem girth (8.3 mm) and flower count (2.91) were highest for cocopeat-grown cucumbers irrigated at 100 % ET_c. The highest LAI (0.065) was obtained from plants grown on So + CRH at 100 % ET_c. The highest leaf chlorophyll content (74 spad) was obtained from cucumber grown on soil at 75 % ET_c whereas the highest abortion accounted for resulted from So + CRH grown plants at irrigated at 75 % ET_c (3.76).

Plants irrigated with 100 % ET_c accounted for the highest yield (t/ha), highest fruit number (3.95) and highest weight of (342.4g). The longest plants were those grown on CP at 100 % ET_c.

Use of drip irrigation in the greenhouse has proven to be a worthwhile effort over the years both in terms of efficiency and effectiveness, especially in areas like Northern Ghana where water is limited and therefore needs to be channeled to the right quarters. That is, optimal use of water at all crop stages is ensured. Adoption of soilless media for cucumber cultivation in the greenhouse also helps in improving productivity by overcoming some of the disadvantages associated with soil especially soil borne diseases which impairs crop growth. Cocopeat, although not easily accessible in this part of the world, it is a good organic media in vegetable production as it gives room for optimum growth. Rice husk, a by - product from rice processing, is highly abundant and usually left as waste material. When charred, it has the capability of improving the physico-chemical properties of soil such as bulk density and water holding capacity, basically through its additional effect on soil organic matter.

Based on the objectives of this research, the following conclusions can be made:

- Plants irrigated at 100 % ET_c performed best for most of the growth parameters including plant height, number of leaves, stem girth, leaf area index and flower count.

- Irrigating cucumber plants at 75 % ET_c resulted in highest chlorophyll content. This is however closely followed by those irrigated at 50 % ET_c whereas those irrigated at 100 % ET_c recorded the lowest chlorophyll content.

- Based on physio – chemical properties of the media, CP had the lowest bulk density while So had the highest. This invariably gave rise to highest moisture content and available water capacity in CP and lowest in So. The highest flower count in CP – grown plants in contrast to So – grown plants can be associated to this.

- CP highly facilitated plant growth as it accounted for the highest plant height, number of leaves and number of flowers.
- So + CRH however had the best performance in terms of indices such as: stem girth and leaf area index. Plants grown on So had the highest chlorophyll content.
- Though So + CRH did relatively well for some of the growth indices, it however gave the highest flower abortion when irrigated at 75 % ET_c.
- CP grown cucumber plants irrigated at 100 % ET_c gave the highest plant height, number of leaves, stem girth and flower count. However, Soil-grown plants at 75 % ET_c gave the highest chlorophyll content. So + CRH grown plants irrigated at 100 % ET_c gave the highest LAI. However, the highest number of flowers were aborted on So + CRH grown plants irrigated at 75 % ET_c.
- Plants irrigated at 100 % ET_c accounted maximum yield of greenhouse grown cucumber.
- Although CP gave the highest yield, the high cost of obtaining it made it less used as compared with So.
- Cucumber production in CP under greenhouse conditions gave highest profit of GH₵702, it is however not the most profitable as it gave a BCR of 1.20 as compared to 1.27 given by So.
- So + CRH gave the lowest BCR due to having the lowest benefit, associated to the high flower abortion

5.2 RECOMMENDATIONS

- The differences between CP-grown plants irrigated at 100 and 75 % ET_c was not significant in relation to some of the growth indices and even yield. It is therefore recommended for cucumber growers in the greenhouse to make use of CP at 75 % ET_c, in order to maximize yield while saving water.

- So + CRH grown cucumber performed best in terms of some growth indices, Soil is better used in greenhouses when it is mixed with charred rice husk (75:25), this is good in areas like Northern Ghana where rice husk is readily available

- Due to the cost implication of availing CP and the ease of assessing CRH in Ghana, more work could be done on combining CP or other soilless media with CRH as a media for cucumber cultivation, as CRH has the ability to increase the nutrient status of the plant when mixed with other media in contrast to when used alone.

- Comparative research may be conducted in the field and greenhouse to confirm their effects in cucumber production in Ghana.

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APPENDICES

Appendix 1: Crop Water Requirement for Cucumber Plant grown on So and So + CRH with Deficit Levels

Month	Decade	Stage	K_c coeff	ET_o mm/day	ET_c mm/day	ET_c mm/dec	100 % ET_c	75 % ET_c	50 % ET_c
Jun	3	Init	0.70	4.03	2.82	2.80	2.80	2.10	1.40
Jul	1	Init	0.70	3.97	2.78	27.80	27.80	20.85	13.90
Jul	2	Deve	0.71	3.93	2.79	27.90	27.90	20.93	13.95
Jul	3	Deve	0.80	3.81	3.05	33.50	33.50	25.13	16.75
Aug	1	Mid	0.88	3.73	3.28	32.80	32.80	24.60	16.40
Aug	2	Mid	0.89	3.62	3.22	32.20	32.20	24.15	16.10
Aug	3	Late	0.89	3.69	3.28	36.10	36.10	27.08	18.05
Sep	1	Late	0.85	3.77	3.20	32.00	32.00	24.00	16.00
Sep	2	Late	0.81	3.83	3.10	12.40	12.40	9.30	6.20
						237.40	237.40	178.13	118.75

Appendix 2: Crop Water Requirement for Cucumber Plant grown on CP with Deficit Levels

Month	Decade	Stage	K_c	ET_o	ET_c	ET_c	100 % ET_c	75 % ET_c	50 % ET_c
			coeff	mm/day	mm/day	mm/dec	mm/dec	mm/dec	mm/dec
Jun	3	Init	0.70	4.01	2.81	2.80	2.80	2.10	1.40
Jul	1	Init	0.70	3.96	2.77	27.70	27.70	20.78	13.85
Jul	2	Deve	0.71	3.92	2.78	27.80	27.80	20.85	13.90
Jul	3	Deve	0.80	3.80	3.04	33.50	33.50	25.13	16.75
Aug	1	Mid	0.88	3.72	3.27	32.70	32.70	24.53	16.35
Aug	2	Mid	0.89	3.62	3.22	32.20	32.20	24.15	16.10
Aug	3	Late	0.89	3.69	3.28	36.10	36.10	27.08	18.05
Sep	1	Late	0.85	3.77	3.20	32.00	32.00	24.00	16.00
Sep	2	Late	0.81	3.83	3.10	12.40	12.40	9.30	6.20
						237.20	237.20	177.90	118.60

Eto = Reference Evapotranspiration, ETc = Crop evapotranspiration. mm/day = millimeter per day. mm/ dec = millimeter per decade. Init = Initial stage. Dev = development stage

Appendix 3: Distribution Uniformity Test values mm^3/ day

Replication	DU (%)	Q (l / h)
Replication 1	0.86	0.70
Replication 2	0.86	0.88
Replication3	0.92	0.72

DU = distribution uniformity, Q =discharge, l/h = liter per hour

Appendix 4: Analysis of variance for chlorophyll content at 2 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	668.80	334.40	4.26	0.031
MEDIA	2	4245.62	2122.81	27.02	<.001
IRRIGATION.MEDIA	4	722.83	180.71	2.30	0.098
Residual	18	1414.40	78.58		
Total	26	7051.66			

Appendix 5: Analysis of variance for chlorophyll content at **4 WAT**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	720.2	360.1	1.79	0.195
MEDIA	2	2107.4	1053.7	5.24	0.016
IRRIGATION.MEDIA	4	1242.0	310.5	1.55	0.232
Residual	18	3616.3	200.9		
Total	26	7685.9			

Appendix 6: Analysis of variance for chlorophyll content at 6 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	726.9	363.5	1.47	0.257
MEDIA	2	291.8	145.9	0.59	0.566
IRRIGATION.MEDIA	4	581.1	145.3	0.59	0.677
Residual	18	4462.5	247.9		
Total	26	6062.4			

Appendix 7: Analysis of variance for LAI at 2 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	0.00002222	0.00001111	0.30	0.744
MEDIA	2	0.00046667	0.00023333	6.30	0.008
IRRIGATION.MEDIA	4	0.00044444	0.00011111	3.00	0.046
Residual	18	0.00066667	0.00003704		
Total	26	0.00160000			

Appendix 8: **Analysis of variance for LAI at 4 WAT**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	0.00009116	0.00004558	0.94	0.410
MEDIA	2	0.00037637	0.00018818	3.87	0.040
IRRIGATION.MEDIA	4	0.00023402	0.00005850	1.20	0.343
Residual	18	0.00087437	0.00004858		
Total	26	0.00157592			

Appendix 9: Analysis of variance for LAI at 6 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	0.00058808	0.00029404	6.29	0.008
MEDIA	2	0.00038829	0.00019414	4.16	0.033
IRRIGATION.MEDIA	4	0.00026307	0.00006577	1.41	0.271
Residual	18	0.00084098	0.00004672		
Total	26	0.00208042			

Appendix 10: Analysis of variance for Plant height at 2WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	26.7	13.3	0.11	0.896

MEDIA	2	148.2	74.1	0.62	0.551
IRRIGATION.MEDIA	4	127.2	31.8	0.26	0.897
Residual	18	2165.2	120.3		
Total	26	2467.3			

Appendix 11: Analysis of variance for Plant height at 4 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	727.1	363.5	2.55	0.106
MEDIA	2	453.4	226.7	1.59	0.231
IRRIGATION.MEDIA	4	1131.8	283.0	1.99	0.140
Residual	18	2561.7	142.3		
Total	26	4874.1			

Appendix 12: Analysis of variance for Plant height at 6 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	3987.1	1993.5	5.50	0.014
MEDIA	2	787.3	393.7	1.09	0.358
IRRIGATION.MEDIA	4	232.1	58.0	0.16	0.956
Residual	18	6520.3	362.2		
Total	26	11526.8			

Appendix 13: **Analysis of variance for number of leaves at 2WAT**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	0.01568	0.00784	0.37	0.696
MEDIA	2	0.01313	0.00656	0.31	0.738
IRRIGATION.MEDIA	4	0.02857	0.00714	0.34	0.849
Residual	18	0.38150	0.02119		
Total	26	0.43887			

Appendix 14: Analysis of variance for number of leaves at 4 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	0.10459	0.05229	1.60	0.230
MEDIA	2	0.05186	0.02593	0.79	0.468
IRRIGATION.MEDIA	4	0.23350	0.05838	1.78	0.177
Residual	18	0.58991	0.03277		
Total	26	0.97986			

Appendix 15: Analysis of variance for number of leaves at 6 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	1.27904	0.63952	9.62	0.001
MEDIA	2	0.05252	0.02626	0.39	0.679
IRRIGATION.MEDIA	4	0.15320	0.03830	0.58	0.684
Residual	18	1.19717	0.06651		
Total	26	2.68193			

Appendix 16: Analysis of variance for stem girth at 2 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	0.2965	0.1483	1.00	0.388
MEDIA	2	0.8001	0.4000	2.70	0.095
IRRIGATION.MEDIA	4	1.3733	0.3433	2.31	0.097
Residual	18	2.6701	0.1483		
Total	26	5.1401			

Appendix 17: Analysis of variance for stem girth at 4 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	3.9879	1.9939	11.93	<.001
MEDIA	2	0.3191	0.1595	0.95	0.404

IRRIGATION.MEDIA	4	0.7952	0.1988	1.19	0.349
Residual	18	3.0091	0.1672		
Total	26	8.1112			

Appendix 18: Analysis of variance for stem girth at 6 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	2.554	1.277	0.64	0.539
MEDIA	2	5.127	2.563	1.28	0.301
IRRIGATION.MEDIA	4	1.311	0.328	0.16	0.954
Residual	18	35.922	1.996		
Total	26	44.914			

Appendix 19: Analysis of variance for flower count at 3 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	0.14281	0.07140	5.56	0.013
MEDIA	2	0.22211	0.11105	8.65	0.002
IRRIGATION.MEDIA	4	0.31513	0.07878	6.14	0.003
Residual	18	0.23097	0.01283		
Total	26	0.91102			

Appendix 20: Analysis of variance for flower count at 4 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	0.62599	0.31300	4.74	0.022
MEDIA	2	0.87886	0.43943	6.66	0.007
IRRIGATION.MEDIA	4	0.07616	0.01904	0.29	0.882
Residual	18	1.18812	0.06601		
Total	26	2.76914			

Appendix 21: Analysis of variance for flower count at 5 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	0.9783	0.4891	3.14	0.068
MEDIA	2	0.3978	0.1989	1.28	0.303
IRRIGATION.MEDIA	4	0.3183	0.0796	0.51	0.729
Residual	18	2.8051	0.1558		
Total	26	4.4995			

Appendix 22: Analysis of variance for flower count at 6 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	1.0990	0.5495	3.83	0.041
MEDIA	2	0.0399	0.0200	0.14	0.871
IRRIGATION.MEDIA	4	0.5826	0.1457	1.02	0.426
Residual	18	2.5831	0.1435		
Total	26	4.3046			

Appendix 23: Analysis of variance for flower abortion at 4 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	0.00831	0.00415	0.05	0.954
MEDIA	2	1.04912	0.52456	5.92	0.011
IRRIGATION.MEDIA	4	0.55509	0.13877	1.57	0.226
Residual	18	1.59461	0.08859		
Total	26	3.20713			

Appendix 24. Analysis of variance for flower abortion at 5 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	0.03643	0.01822	0.66	0.529
MEDIA	2	0.67808	0.33904	12.28	<.001

IRRIGATION.MEDIA	4	0.35946	0.08986	3.25	0.036
Residual	18	0.49705	0.02761		
Total	26	1.57103			

Appendix 25. Analysis of variance for flower abortion at 6 WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	0.10692	0.05346	1.35	0.284
MEDIA	2	0.10066	0.05033	1.27	0.304
IRRIGATION.MEDIA	4	0.10982	0.02746	0.69	0.606
Residual	18	0.71257	0.03959		
Total	26	1.02998			

Appendix 26. Analysis of variance for average fruit diameter per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	20.36	10.18	0.89	0.428
MEDIA	2	2.64	1.32	0.12	0.892
IRRIGATION.MEDIA	4	40.71	10.18	0.89	0.489
Residual	18	205.61	11.42		
Total	26	269.32			

Appendix 27. Analysis of variance for average fruit length per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	47.097	23.549	6.85	0.006
MEDIA	2	2.264	1.132	0.33	0.724
IRRIGATION.MEDIA	4	50.556	12.639	3.68	0.023
Residual	18	61.875	3.438		

Total	26	161.792			

Appendix 28. Analysis of variance for average fruit weight per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	18515.	9258.	4.46	0.027
MEDIA	2	693.	347.	0.17	0.847
IRRIGATION.MEDIA	4	16409.	4102.	1.98	0.141
Residual	18	37329.	2074.		
Total	26	72946.			

Appendix 29. Analysis of variance for average number of fruits per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	9.5602	4.7801	12.67	<.001
MEDIA	2	1.3293	0.6647	1.76	0.200
IRRIGATION.MEDIA	4	0.3521	0.0880	0.23	0.916
Residual	18	6.7895	0.3772		
Total	26	18.0312			

Appendix 30. Analysis of variance for average yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
IRRIGATION	2	27997.1	13998.5	22.38	<.001
MEDIA	2	2944.4	1472.2	2.35	0.124
IRRIGATION.MEDIA	4	3471.0	867.8	1.39	0.278
Residual	18	11257.5	625.4		
Total	26	45670.0			

Appendix 31: Rice husk charring

Appendix 32: Left: PWP and FC test in the laboratory; Right: Sample weighing for EC and P^H tests


Appendix 33: Potting of media


Appendix 34: Left: Nursery at germination; Right: Nursery at transplanting


Appendix 35: Left: Downew-mildew incidence on soil-grown cucumber at 2 WAT. Right: Transplants at 3 WAT

Appendix 36: Left: Transplants at 4 WAT; Right: Transplants at 5 WAT

Appendix 37: Left: Measuring plant stem girth at 6 WAT; Right: Measuring plant chlorophyll content at 6 WAT

Appendix 38: Cucumber fruits at harvest (6 WAT)

Appendix 39: left: Harvesting; Right: Fungicide application