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Soilless Cucumber Cultivation under Protective Structures in Relation to Irrigation Coupled Fertigation Management, Economic Viability and Potential Benefits-A Review

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A B S T R A C T

The protected cultivation of cucumber in soilless systems (substrate culture, hydroponic, aeroponic etc.) under optimal operating microclimatic conditions has become an alternative for sustainable vegetable production as a result of shifting climatic scenarios and soil related problems. The soilless cultivation in both open and closed systems with efficient utilization of water and nutrients has significantly increased the greenhouse cucumber productivity compared to conventional cultivation under both protective structures and open field conditions. A closed hydroponic system has helped in saving water and nutrients thereby increasing water and nutrient use efficiency of cucumber cultivation with no environmental pollution. Further, the year round cultivation of cucumber has become possible under protective structures making it as an economically viable technology for the growers. Here, an effort has been made to highlight the progress made in soilless or hydroponic cucumber cultivation in past in relation to irrigation coupled fertigation management, economic viability and the potential benefits. The study also describes the methods for computing the components of water and nutrient use balance in both open and closed systems.

Introduction

Cucumber (*Cucumis sativus* L.) is one of the most popular vegetable crops cultivated broadly throughout the world (Soleimani *et al.*, 2009) under plastic greenhouses for higher economic value in off-season cultivation (Chandra *et al.*, 2000). It is thermophilic in nature and frost susceptible crop (Bacci *et al.*, 2006), growing best at a temperature above 22.0°C and below 27.0°C (Singh *et al.*, 2017a). It grows productively under conditions of high humidity, high light, fertilizers and moisture in plastic greenhouses (El-Aidy *et al.*, 2007). It can be planted by direct seeding or transplanting. The row to row spacing is often kept from 120.0 to 150.0 cm and plant to plant spacing varies from 30.0 to 45.0 cm. The suitable plant spacing and pruning results in higher fruit yield of cucumber (More *et al.,* 1990). Cucumber is cultivated for its tender fruits, which are consumed either raw as salad, cooked as vegetable or pickled in its immature stage (Sumathi *et al.,* 2008). For fresh consumption, cucumber fruits are picked at their full growth stage before attainment of physiological maturity (Kanellis *et al.,* 1986) However, the quality and production of cucumber is now in threat under changing climatic scenarios, growing media (occurrence of soil-borne diseases on global basis) and the microclimate within plant community.

Effect of climate change on crop production

The climate change which is one of the main determinants of agricultural production has started affecting the pattern of crop growth from last few couple of decades in various agro-climatic zones globally (Wang *et al.,* 2014). The production and quality is affected directly or indirectly due to increased temperature and exposure to elevated levels of carbon dioxide. According to Minaxi *et al.,* (2011), the expected rise in average surface temperature may be in the range of 1.1°C-6.4°C by the last decade of 21st century on global basis. Any change in climatic factors such as temperature is bound to have a significant impact on crop growth and production (Singh, 2016). In India, climate change has increased the intensity of natural calamities such as floods, droughts, heat waves and cyclones (Goswami *et al.,* 2006). The problems would further aggravate in the years to come due to heavy dependence on agriculture and limited arable land if no corrective measures are taken today. Apart from this, the application of agrochemicals such as fungicide has also limited the production of high value fruits and vegetable crops such as cucumber (Bagi *et al.,* 2014). Numerous factors which affect the cucumber growth and productivity to a significant degree are described in Singh *et al.,* (2017a).

Effect of growing media on crop production

The major limitations of protective cultivation are soil borne diseases (Baysal-Gurel *et al.,* 2012). The soilless cultivation is therefore, a possible alternative for sustainable vegetable production, which reduces the soil related problems experienced in the conventional crop cultivation (Olympious, 1995; Hussain *et al.,* 2014). Moreover, soilless growing media are easier to handle and may provide a better growing environment compared to soil (Mastouri *et al.,* 2005). Soilless cultivation also offers other benefits such as capability to control water availability, pH and nutrient concentration in the root zone (Epstein and Bloom, 2005). Cocopeat is one of the soilless media which is suitable for cucumber production. The major limitations of protective cultivation are soil borne diseases (Baysal-Gurel *et al.,* 2012). The soilless cultivation is therefore, a possible alternative for sustainable vegetable production, which reduces the soil related problems experienced in the conventional crop cultivation (Olympious, 1995; Hussain *et al.,* 2014). Moreover, soilless growing media are easier to handle and may provide a better growing environment compared to soil (Mastouri *et al.,* 2005). Soilless cultivation also offers other benefits such as capability to control water availability, pH and nutrient concentration in the root zone (Epstein and Bloom, 2005). Cocopeat is one of the soilless media which is suitable for cucumber production. The present study was thus undertaken to study the nutrient and water use efficiencies of greenhouse seedless cucumber production in soilless media under partially controlled greenhouse conditions.

The soil borne diseases both in protective structures and open field conditions have limited the cucumber cultivation (Baysal-Gurel *et al.,* 2012). Under such circumstances, the soilless cultivation can be practiced for sustainable vegetable production, with a significant reduction in soil related problems experienced in the conventional cultivation (Olympious, 1995; Hussain *et al.,* 2014). Furthermore, soilless growing systems (substrate culture, hydroponic, aeroponic or aquaponic etc.) may provide a better growing environment and are easier to handle compared to soil (Mastouri *et al.,* 2005). It also offers other benefits such as capability to control pH and nutrient concentration in the root zone and water availability (Epstein and Bloom, 2005).

Microclimate within plant community

The productivity of cucumber grown inside protective structure is extremely dependent on light, humidity, temperature, CO_2, irrigation water, fertigation, method of cultivation and cultivars. The crop productivity also chiefly depends on the response of plants to environmental conditions. According to Marcelis *et al.,* (2005), the yield of vegetable crops reduces by 0.8-1.0 percent for 1.0 percent reduction of solar radiation reaching the plant canopy. From biomass production and energy saving point of view, an air temperature of 19.0°C for daytime and 15.0°C for night time and a canopy leaf area index (LAI) of 2.0-3.0 provides the most energy efficient conditions for greenhouse cucumber cultivation under the winter climate conditions (Luo *et al.,* 2005). It is thus important to cultivate cucumbers under protective structures under optimal operating microclimatic conditions for improved yield and quality of fruit.

Protected cultivation

A protective structure when supported with favorable climatic conditions offers off-season cultivation of vegetable crops which is more profitable in the Northern Plains of India (Nair and Barche 2014). A greenhouse traps solar radiation of short wavelengths to create an encouraging microclimate for plant growth and higher productivity (Tiwari 2006). In the present scenario of continual demand of vegetables and dwindling land holdings drastically, protected cultivation of vegetable crops is also becoming popular in the hilly regions of the country, which offers a great scope for use of low cost naturally-ventilated polyhouses or greenhouses because of mild climate (Mishra *et al.,* 2010). Thus, protected cultivation is now very much needed under Indian conditions to improve the productivity and quality of the vegetable crops (Kohli *et al.,* 2007).

According to Spehia (2015), the productivity of cucumber inside a polyhouse is more than four times of that obtained under open field cultivation. Kumar *et al.,* (2011) reported a 2.5 times increase in vegetable production from 1991-92 to 2010-11 in India. FAO (2011) has reported a cucumber production of 1.60 lakh tonnes with an average productivity of 6412.0 kg ha^{-1} from an area of 25104.0 ha in India. The worldwide area under protected cultivation has increased significantly during past couple of decades (Singh *et al.,* 2016). India, from where the cucumber originated is not among the leading global producers. However, the cucumber productivity and fruit quality in soil under protective structures has been significantly reduced due to soil-borne dieases (Hussain *et al.,* 2014). Thus, soilless cultivation can be adopted for sustainable vegetable production.

Soilless cultivation

The soilless cultivation is a technique of growing crops without soil as rooting media (Savvas *et al.,* 2013). It has been acknowledged internationally due to its ability to maintain efficient and intensive plant production (Barrett *et al.,* 2016). It has become progressively more important worldwide during last fifty years (Schmilewski 2009). In recent past, numerous researchers cultivated cucumbers in soilless media under different greenhouse conditions (Huber *et al.,* 2005; Gul *et al.,* 2006; Gul *et al.,* 2007; Janapriya *et al.,* 2010; Zhang *et al.,* 2012; Mazahreh *et al.,* 2015). Subjected to optimal operating microclimatic conditions for greenhouse cucumber cultivation in soilless media (Singh *et al.,* 2017b), desired yield potential of cucumber can be achieved.

Optimal microclimate for cucumber cultivation

The assemblage of climatological parameters forming around a living plant inside a protective strucutre is termed as greenhouse microclimate (Singh *et al.,* 2016). Thus, it becomes important to maintain the microclimatic parameters to a desired range for better crop growth and productivity through commonly used techniques viz. natural ventilation, shading and evaporative cooling under summer climatic conditions (Singh *et al.,* 2018) and heating in winter climatic conditions. Most recently, Singh *et al.,* (2017b) reported the desirable range for air temperature in plant community, leaf temperature and root-zone temperature as 22.0-27.0°C, 20.5-25.1°C, 16.9-22.9°C respectively. According to Singh *et al.,* (2017b), relative humidity, solar radiation and vapour pressure deficit should lie in the range of 60.0-85.0 percent, 100.0-169 Wm^{-2} and 0.53-1.10 kPa respectively for optimal plant growth and development.

Properties of soilless growing media

The knowledge of physiochemical properties of growing media is essential for limiting them to desired range in order to offer better plant growing conditions. These properties viz. particle density, bullk density, air filled porosity, total porosity, moisture content, field capacity, EC and pH value can be determined individually by different methods suggested in literature one of which is reported in Verdonck and Gabriels (1992). EC and pH values are the most sensitive parameters which directly affect the water and nutrient uptake of the plants which in turn can limit the plant growth and development.

Among several growing media, coco-peat is considered as a wonderful growing media with suitable EC, pH and other chemical properties. Coco-peat has high water holding capacity and its high air filled porosity results in very high seed germination rate and produces more stronger and fibrous seedlings (Fornes *et al.,* 2003). According to Ghehsareh *et al.,* (2011), the water holding capacity (WHC) of coco-peat is 90.5 percent, while other substrates such as perlite and date-palm peat are having WHC of 96.7 percent and 78.3 percent respectively.

Nutrients requirement of cucumber

The cucumber plants grown in soilless media require a continuous supply of nutrient solution containing both macro and micronutrients in appropriate proportion based on crop growth stage. The elements *viz.* carbon (C), hydrogen (H) and oxygen (O) are also essentially required by the plants and obtained from water and air. The nutrients (macro) are categorized as primary and secondary macronutrients. The primary macronutrients included nitrogen (N), phosphorus (P) and potassium (K) and the secondary macronutrients included calcium (Ca), magnesium (Mg) and sulphur (S). The micronutrients included boron (B), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn) and molybdenum (Mo). The micronutrients are required by plants in small quantities. The water soluble fertilizers are now easily available in market and can be used as the sources of macro and micronutrients.

Preparation of nutrient solution

The nutrient solution can be prepared on daily basis if possible or stock solution (hogland) can be prepared according to literature (Hoagland and Arnon 1950; Sonneveld and Straver 1994). The prepared nutrient solution should be monitored on regular basis for EC, pH value and deficiency of micronutrients as suggested by Shah *et al.,* (2009).

Disposal of leachate

Suitable arrangement should be made to safely dispose off the leachate coming out of the growing media in open system. In closed system, the leachate is recirculated and reused causing no environmental pollution.

pH and EC of nutrient solution

The parameter pH is directly related to nutrient uptake by plants and should be adjusted to desired range for optimal plant growth. Several chemicals can be used to adjust the pH of nutrient solutions.

The most popular are phosphoric acid to lower pH and potassium hydroxide to raise pH. Other chemicals *viz*. mono potassium phosphate, nitric acid and sulfuric acid can also be used to lower pH. However, nitric acid and sulfuric acid are much more dangerous than phosphoric acid. The pH value of the nutrient solution should be kept in the range of 6.0-6.40.

On the other hand, the increased EC value of nutrient solution may consequently increase the acidity (Adams and Ho 1989) thereby affecting the crop growth and development. Cucumber is moderately salt-sensitive among the vegetable crops having threshold EC value of 3.0 dS m^{-1} (Singh *et al.,* 2017a). The preferable EC of nutrient solution is 2.7 dS m^{-1} and should never exceed 3.0 dS m^{-1} to avoid the yield penalty (Sonneveld and Voogt 2009). The EC and pH values of nutrient solution and growing media can be monitored on daily basis using water proof testers.

Method of irrigation coupled fertigation

Drip irrigation is the most suitable method for irrigating vegetable or fruit crops in both soil and soilless media. It is considered as a tool for increasing water and nutrient use efficiency (NUE) of the crop grown when managed carefully. It maximizes yield with a significant reduction in input water and environmental pollution by improving the photosynthetic capacity of the plants. It minimizes the leaching of nutrients or chemicals from root-zone system of the plants (Gardenas *et al.,* 2005). Numerous studies reported the positive effect of drip irrigation in improving yield of the crop grown (Ertek *et al.,* 2006; Vazquez *et al.,* 2006; Castellanos *et al.,* 2013).

Crop water requirement

The crop water requirement (CWR) can be estimated from crop transpiration under a closed soilless or hydroponic system. The crop transpiration can be computed using the formula derived from the Penman-Monteith equation (Medrano *et al.,* 2005) with certain modifications in model coefficients (equation 1). Transpiration helps to improve irrigation control in soilless cultivation of crops under greenhouse conditions as it is directly related to plant production (Watts and Goltz 1985). Numerous studies related to transpiration from cucumber crop (evapotranspiration) have been reported in literature (Medrano *et al.,* 2001; Weihong *et al.,* 2004; Medrano *et al.,* 2005; Zhang *et al.,* 2010).

A simplified model derived from Penman-Montheith equation with a few modifications in model coefficients for specific cop and climatic conditions can accurately predict the hourly transpiration rate for soilless cucumber crop (Medrano *et al.*, 2001, 2005). Weihong *et al.*, (2004) also computed the canopy transpiration of cucumber crop using Penman-Monteith model. Medrano *et al.*, (2005) evaluated the transpiration time course of cucumber plants cultivated in soilless culture during two cycles at low (up to 9.0 M J m^{-2} d^{-1}) and high (up to 20.0 M J m^{-2} d^{-1}) radiation levels. Zhang *et al.*, (2010) studied the relationship between crop evapotranspiration (ET_c) of cucumber and climatic factors inside a solar greenhouse.

$$T = \frac{A \times (1 - e^{-k \times LAI}) \times I_{rad} + B \times LAI \times VPD}{\lambda} \quad (1)$$

Where, T = Crop transpiration (kg m^{-2} s^{-1}), I_{rad} = Solar radiation (W m^{-2}), VPD =Vapour pressure deficit (kPa), k = Extinction coefficient, LAI = Leaf area index (m^2 m^{-2}), λ = Heat of vaporization of water (J kg^{-1}), A = Equation parameter (dimensionless) and B = Equation parameter (W m^{-2} kPa^{-1})

The parameters A and B are different for different seasons.

Fertigation system

A drip fertigation system generally includes main pipeline, laterals and emitter pipe for supplying nutrient solution to the plants. The system also includes tanks for preparation of nutrient solution, electric motors or solar system, pressure gauges, timers, filters and emitters. The operating pressure of emitters can be regulated using pressure gauge to deliver the nutrient solution safely and at desired rate to the root zone of the plants. The timers allow the application of nutrient solution for a pre-determined time. The nutrient solution should be passed through filters for each supply before its delivery to the plant root system to prevent the clogging of emitters. The nutrient solution is supplied directly to the plants root system through emitters operating at a desired discharge rate.

Computation of water and nutrient balance

In soilless cultivation, the quantity of nutrient solution applied to the crop on daily basis can be measured by means of measuring cylinders installed at various locations.

Volume of water application

The total volume (V_{nsapp} or V_{wapp}) of nutrient solution applied per plant per day in a given time (t) can be calculated for a known discharge rate of an emitter using the following relationship.

$$V_{wapp} = n \times q \times t \quad (2)$$

Where, n = Total number of emitters operating, q = Emitter discharge (litre hr^{-1}) and t = Time to irrigate or fertigate (hr)

If V_{wupp} and V_{wdpp} be the volume of water uptake and water drained per plant, the water balance can be expressed as

$$\Delta V_{ws} = V_{wapp} - V_{wdpp} - V_{wupp} \quad (3)$$

Where, V_{wapp} = Volume of water applied per plant (litre plant^{-1}) and ΔV_{ws} = Water stored in growing media on volumetric basis.

However for a closed hydroponic system where only plant roots are in contact with running nutrient solution, ΔV_{ws} can be taken as zero and the equation 4 becomes as

$$V_{wapp} - V_{wdpp} - V_{wupp} = 0 \quad (4)$$

Nutrient balance

For measurement of leachate coming out of the growing media specially designed trays can be installed at different locations in the experimental trial. The collected leachate or waste nutrient solution can be measured using a measuring cylinder on daily basis and can be recycled for further use in a closed system. Having known the total volume of nutrient solution applied on daily basis and the concentration of each nutrient in the applied nutrient solution, the quantity of applied nutrient to the crop can be computed as $NA_{pp} = c_{ans} \times V_{nsapp}$ (5)

Where, TNA_{pp} = Total nutrient applied per plant (mg plant^{-1}), c_{ans} = Concentration of a nutrient in the applied nutrient solution (mg litre^{-1}) and V_{nsapp} = Total volume of nutrient solution applied per plant (litre plant^{-1})

The nutrient concentration of plant can be computed analytically using inductively coupled plasma atomic emission spectroscopy (ICP-AES) except for nitrogen (Grewal *et al.,* 2011). The oven dried samples of leaves, stems and fruits are used for determination of nutrient elements. The concentration of nitrogen present in plant in amonical form can be computed using standard ethods such as Kjeldahl digestion method. The total plant uptake of the nutrient for each element can be computed as

$$NU_{pp} = c_L dw_L + c_S dw_S + c_F dw_F \quad (6)$$

Where, NU_{pp} = Nutrient uptake per plant (mg plant^{-1}), c_L =Concentration of a nutrient in leaves (ppm), c_S = Concentration of a nutrient in stems (ppm), c_F = Concentration of a nutrient in fruits (ppm), dw_L = Dry weight of leaves (mg plant^{-1}), dw_S = Dry weight of stems (mg plant^{-1}), dw_F = Dry weight of fruits (mg plant^{-1}).

The nutrient drained can be computed as ND_{pp} = $NA_{pp} - NU_{pp}$ (7)

Where, ND_{pp} = Total nutrient drained per plant (mg plant^{-1})

The total nutrient applied, plant uptake and nutrient drained can be computed on per plant and per hectare basis (kg ha^{-1}). The nutrient balance in an open soilless growing media can be expressed as

$$\Delta N_{sgm} = NA_{pp} - NU_{pp} - ND_{pp} \quad (8)$$

Where, ΔN_{sgm} = Nutrient storage in growing media (mg plant^{-1})

However, the nutrient balance for a closed hydroponic system can be expressed as

$$NA_{pp} - NU_{pp} - ND_{pp} = 0 \quad (9)$$

Pollination

In cucumber, the male flowers emerge first and female flowers shortly later. A female flower contains a small immature fruit at the base while the male flower does not contain any. Pollen is transferred from male to female flower by bees or other insects. After proper pollination the female flower develops into a fruit. However, the parthenocarpic cucumber hybrids produce fruits without pollination. Greenhouse cucumbers are naturally parthenocarpic and the fruits produced are seedless.

Disease management

The main entry gate of the greenhouse under experimentation should be provided with an air curtain to create a barrier between outside and inside air and blow away the insects entering the greenhouse during entry of a personal. The insect net (if any) of the greenhouse should be washed with a spray of water under adequate pressure in order to remove insects attached to it before transplanting. The yellow sticky cards can be installed in the whole greenhouse at various locations for controlling the whiteflies incidence to the crop and a spray of Polo (Diafenthiuron 50.0 % WP) can also be done before date of transplanting. The growing media should be disinfected before using it for growing cucumbers next growing season. Fungicides such as Ridomil Gold of Syngenta which is a mixture of systemic and contact fungicide (Metalaxyl-M4.0%+Mancozeb 64.0% WP) can be used for disinfecting the growing media.

Irrigation coupled fertigation

Water and nutrients are two vital inputs for plant growth particularly in soilless media and their uptake by plants are two independent processes. Cucumber is considered to be sensitive to drought stress and should never be short of water (Loomis and Crandall 1977) and nutrients. Fertigation in soilless cultivation provides efficient use of water and nutrients (Jensen 1997) through precise and uniform application of nutrients directly to the active root system of the plant (Rouphael *et al.,* 2008). Numerous researchers studied the effect of irrigation amount (Mao *et al.,* 2003; Amer *et al.,* 2009; Salcedo *et al.,* 2017) and fertilizer coupled irrigation i.e. fertigation (Papadopoulos 2001; Lee *et al.,* 2005; Ahmet *et al.,* 2006; Zhang *et al.,* 2011) on cucumber yield and water use efficiency (WUE).

The recommended fertilizers for fertigating cucumbers in soil and soilless systems can be taken from Anon (2018a). The fertigation schedule or nutrients (macro and micro nutrients) required for preparing nutrient solution to fertigate soilless (hydroponic and substrate based) cucumbers can be taken from Anon (2018b) or Anon (2018c) or Papadopoulos (2001).

Water and nutrient use efficiency

The water use efficiency decreases with increase in irrigation water applied from fruiting to the end of growth stage and increases with increase in irrigation water from cucumber fruit setting to start of fruit ripening (Mao *et al.,* 2003). According to Wang *et al.,* (2009) the IWUE decreased with decrease in water input which also agrees with Ayas and Demirtas (2009). A continous effort has been made in the past to study the effect of irrigation (Sanchez-Guerrero *et al.,* 2009; Grewal *et al.,* 2011) on cucumber growth, yield and quality.

The greenhouse seedless cucumber has a high nutrient requirement and is very productive with adequate supply of nutrients (Sonneveld and Voogt 1978). Drip fertigation allows precise and uniform distribution of water and nutrients exactly to the root system of plant at right time. According to van Os (1999), a soilless system has higher water and nutrient use efficiencies [IWUE or CWUE = yield (kg plant^{-1})/irrigation water applied (m^{3} plant^{-1}) and NUE = yield (kg plant^{-1})/nutrient applied (g plant^{-1})]. A continous effort has been made in the past to study the effect of fertigation (Gul *et al.,* 2007) on cucumber growth, yield and quality.

While comparing the effect of open and closed systems on cucumbers cultivated in vertical and horizontal bags fertigated with applied and drained nutrient solution, Tuzel *et al.,*

(1999) confirmed a 22.0 and 35.0 % reduction in water and nutrient consumption under closed system. According to Papadopoulos (2001), the optimal nutrient application to a crop throughout the entire cropping season in relation to changing needs of the plants for nutrients is highly successful due to a greatly improved understanding of plant nutrition and the availability of sophisticated nutrient delivery systems. Huber *et al.,* (2005) cultivated cucumbers in a specially designed urethane based recyclable plant growth substrate (UBS) and rockwool (RW) under a recirculating hydroponic system and confirmed that irrigation was extremely important for crop production with a potential for UBS to evolve as a competitive plant growth substrate for greenhouse soilless crop production with some design modifications. Lee *et al.,* (2005) reported increased plant weight, number of leaves and total yield including marketable yield with increased application of nutrient solution from 0.5 to 2.0 litre plant^{-1}day^{-1} obtaining highest fruit yields at 1.5 and 2.0 litre plant^{-1} day^{-1} of fertigation level. While evaluating the effect of nutrient sources, organic manure and inorganic conventional nutrient solution on cucumber cultivation in different locally available substrates, Gul *et al.,* (2007) indicated a yield reduction of 10.8% and 31.3% under organic nutrient solution and solid organic manure compared to inorganic nutrient solution.

While testing an EC-based irrigation strategy in two greenhouse soilless cucumber crops grown under Mediterranean conditions, Sanchez-Guerrero *et al.,* (2009) concluded that CO_2 enrichment combined to an EC-based irrigation scheduling improved the overall water use efficiency of soilless greenhouse cropping systems with a drastic reduction of the leaching fraction. Grewal *et al.,* (2011) confirmed a 33.0% reduction in potable water used for irrigation in hydroponic cucumber production while investigating the opportunities in recycling drainage water to increase water and nutrient-use efficiency and reduce the environmental impact of the drainage water discharge. Salcedo and Reca (2017) reported a good correlation between the crop water uptake (WU) and the leaf area index (LAI) while evaluating the irrigation water consumption of a soilless cucumber crop under greenhouse conditions under a humid tropical climate in order to improve the irrigation water and fertigation management.

Effect of growing media on nursery raising and fruit quality of cucumber

Selection of a suitable growing media is extremely important as it influences the quality of seedlings produced. The growing media influences the performance of the ready seedlings before transplanting in the field and the performance of seedlings in the main field after transplanting is evaluated based on their performance in the nursery raising in relation to growing media and microclimatic conditions offered. According to Luoto (1984), the colour of cucumber is affected by growing media at the end of harvest season. The quality of cucumber fruits can be tested by determining texture, colour and taste by either chemical analysis or sensory evaluation (Luoto 1984).

Cucumber contains about 95.2% water, 1.7% sugar and 2.8 mg (100g)$^{-1}$ vitamin C. Melo *et al.,* (2006) have reported the polyphenol concentration of 9.05±0.83 mg (100g)$^{-1}$ and ascorbic acid concentration of 1.49±0.85 mg (100g)$^{-1}$ in cucumber. Firmness is one of the major quality parameters of pickling cucumbers (Suojala-Ahlfors 2005). However, the transpiration from the cucumber fruits detached from the plants considerably reduces the fruit water content and therefore the fruit firmness. The chlorophyll present in the epidermis is responsible for dark green colour on the surface of cucumber fruit. The chlorophyll breakdown results in immediate degreening of cucumber fruit and the exposure of cucumber plants to heat stress during fruit development stage causes bitterness of fruits. The nutritional and calorific value of cucumber is very low, but it is a primary source of vitamins, minerals and fibre for human body. It is also a wonderful source of carbohydrates and phosphorus (Yawalkar 1985).

Soilless cucumber yield

The cucumber cultivation in soilless system has significantly increased during last couple of decades (Gul *et al.,* 1999; Lorenzo *et al.,* 1999; Tuzel *et al.,* 1999; Huber *et al.,* 2005; Al-Mulla *et al.,* 2008; Janapriya *et al.,* 2010; Zhang *et al.,* 2012; Mazahreh *et al.,* 2015) than soil based cultivation due to occurrence of soil borne diseases. Hickman and Klonsky (1993) reported a yield of 33.0 kg m^{-2} for cucumber cultivated in bag culture inside a greenhouse. Gul *et al.,* (1999) reported no significant difference in plant growth, yield and fruit quality both in open or closed systems while cultivating cucumbers in vertical and horizontal bags containing perlite as growing media in open and closed systems.

However, the plant growth and yield were considerably higher in bags placed horizontally. Lorenzo *et al.,* (1999) obtained a lower yield of cucumber under mulching with white film than conventional soilless culture due to lower temperature of air and growing media in the mulched cucumber during the vegetative development phase, inducing a lower leaf area and LAI thereby reducing the interception of radiation by the cucumbers under mulching.

Al-Mulla *et al.,* (2008) reported higher number of cucumber fruits per plant cultivated in wood straw than date palm straw as growing media. Peyvast *et al.,* (2008) reported a significantly higher fresh weight of cucumber plant grown in peat compared to that in perlite. Alifar *et al.,* (2010) obtained the highest and lowest yield of cucumber fruit from cocopeat and perlite-cocopeat by investigating the effect of five different growing media *viz*. cocopeat, perlite: cocopeat (50:50), perlite: cocopeat: peatmoss (50:20:30 and 50:30:20) and perlite: peat moss on volume basis. Janapriya *et al.,* (2010) reported highest yields of 113.9 t ha^{-1} and 96.1 t ha^{-1} in greenhouse and open field cultivation of cucumber under the treatment peat: vermicompost: sand with a highest benefit-cost ratio of 3.4 with 100.0% drip fertigation inside the greenhouse.

Ghehsareh *et al.,* (2012) reported higher yield, biomass, plant height, root weight, leaf area index (LAI) and total soluble solids (TSS) of cucumber fruit on using date-palm as growing media compared to the conventional soil system. While evaluating the weathered spent mushroom substrate (SMS) as a growing medium for nursery raising of cucumber, Zhang *et al.,* (2012) indicated a better peroformance of plant height, leaf area, fresh weight, dry weight and seedling quality under SMS: vermiculite of 2:1 and SMS: perlite of 4:1 growing media compared to peat and perlite (1:1). While studying the effect for different growing media viz. perlite (1:0), cocopeat grow bag, perlite: cocopeat (1:1) and perlite: cocopeat (1:2) on volume basis on cucumber yield, Mazahreh *et al.,* (2015) reported highest (87.6 t ha^{-1}) and lowest (46.0 t ha^{-1}) yield of cucumber under perlite: cocopeat (1:1) and cocopeat grow bag respectively.

Economic feasibility of cucumber cultivation

The economic viability of cucumber cultivation under protective structures mainly depends on the basic cost of construction of the protective structures (Singh and Kumar 2006). The main objective of protective cultivation of vegetable crops including cucumber is to maximize the production through year-round cultivation with improved quality.

Table.1 Benefit cost ratio of cucumber cultivation

Author	Study site	Growing condition	Variety	Benefit cost ratio
Singh *et al.*, (2007b)	New delhi, India	Cultivated cucumber inside a low-cost naturally ventilated greenhouse	Hasan, Muhasan and Sarig	2.3
Janapriya *et al.*, (2010)	TNAU, Coimbatore, India	Grown cucucmber in a mixture of peat, vermicompost and sand with 100.0% drip fertigation inside the greenhouse	Green long	3.4
Mohammadi and Omid (2010)	Tehran province of Iran	Studied the energy balance of greenhouse cucumber production by collecting the data on cucumber production from fourty three different greenhouses in the Tehran province of Iran	-	2.6
Hakkim and Chand (2014)	Tavanur, Kerala, India	Cultivated cucumber in a naturally ventilated greenhouse	hybrid Hilton F1	3.4

In past, numerous authors studied the economic feasiiblity of cucumber cultivation in soilless and soil based conditions under protective structures (Engindeniz and Tuzel 2003; Engindeniz 2004; Singh *et al.*, 2007b; Cantliffe *et al.*, 2008; Engindeniz and Gul 2009; Mohammadi and Omid 2010; Garcia *et al.*, 2012; Kumar *et al.*, 2015).

The low-cost naturally ventilated greenhouses are more suitable and economical for year-round cucumber cultivation (Singh *et al.*, 2007b). Cantliffe *et al.*, (2008) gathered relevant information from public, private and research sources to create an economic feasibility model for comparing the costs and benefits associated with field-grown slicing cucumbers and concluded that that it was not only economically feasible to produce cucumbers in a greenhouse setting, but the potential profits were significantly greater for greenhouse-grown cucumbers compared to field-grown cucumbers in Florida.

Engindeniz and Tuzel (2003) reported a net profit of \$ 1.3 m^{-2} and \$ 0.1 kg^{-1} for cucumbers while evaluating the economic feasibility of cucumber cultivation under farmer's conditions. Engindeniz (2004) evaluated the economic feasibility of growing greenhouse cucumber in soilless culture system. The study emphasized on economic study and benefit-cost analysis at local level and under grower conditions.

According to the study, the net return obtained from greenhouse cucumbers was US \$ 1.81m^{-2} or US \$ 0.07 kg^{-1}. Engindeniz and Gul (2009) analysed the economic aspects of soilless and soil-based greenhouse cucumber production. The study concluded that the net return obtained from cucumbers grown in a mixture of perlite and zeolite was 1.2 times of that in conventional soil-based production. Kumar *et al.,* (2015) reported a higher cost of cultivation of cucumber under polyhouses and net returns by ₹ 185681.00 and 97138.68 acre^{-1} than open field conditions. The benefit cost ratio of cucumber cultivation under different conditions is reported in Table 1.

Benefits of protective cultivation

Year round cultivation of cucumbers under protective structures is possible.

Naturally ventilated greenhouses are most suitable for year round cultivation of cucumbers.

It offers distinct advantage of productivity, quality and encouraging market price to the growers.

The productivity of cucumber can be increased manifold as compared to open field cultivation.

Protective cultivation of cucumber minimizes the application of agricultural chemicals.

Reduced consumption of water and nutrients in cucumber production.

Benefits of soilless growing media

A growing media serves as a reservoir of plant nutrients, anchors the root system and consequently supports the plant.

It significantly affects the seed germination, succeeding emergence, growth and ultimately the quality of seedlings. A substrate that possesses high water holding capacity along with optimum nutrient and aeration for plant growth is advantageous to nursery growers. A better control on plant nutrition and diseases due to better control water on available water, pH and nutrient concentration in the root zone of plants.

Easier to handle and provide a better growing environment compared to soil.

Reduced intensity of disease occurrence compared to conventional cultivation.

Allows for maximum root growth and support physically the plant.

Increased productivity compared to conventional cultivation or open field conditions.

Saving of water, fertilizer and labour with a significant reduction in insect-pest or disease incidence during continuous cropping and decreased the application of agro-chemicals.

Improved aeration in the root-zone of the plant.

Plants can be moved to a most suited area for better handling whenever required.

The available water per plant is smaller than in soil regardless of the high water holding capacity, low moisture tension and higher hydraulic conductivity for most of the crops grown in the substrates.

No environmental pollution in closed hydroponic system.

Factors limiting cucumber cultivation

Changing climate scenarios.

Inappropriate plant microclimate.

Prevalence of soil borne diseases.

Growing media and nutritional deficiency (calcium, iron and manganese) or excess.

Toxicity occurrence in the crop due to excess of nutrients applied.

Occurrence of whiteflies incidence, mite and fungal diseases.

Senstivity to draught or water stress.

Sensitivity to salt.

EC and pH of nutrient solution and growing media.

Safety measures

The frequent entry to the protective structure where the nursery is raised or crop is grown should be avoided.

While handling the plants such as thinning of plants, hands should be covered with gloves.

Check for incidence of insect-pest incidence (if any) on regular basis.

Check for any leakage in the protective structure through cover which may allow the entry of insects.

Incidence of whiteflies is very common while growing nurseries for cucumber even under protective structures. Primarily, sticky trap cards can be installed inside the structure in plant community.

For controlling incidence of insect-pest or diseases, the insecticide used should be in desired quantity since the overdose may harm the plants.

Fertilizers should also be applied in right amount for not to encourage incidence of diseases.

Irrigate the nursery plants according to the need only.

Allow sufficient ventilation for air exchange between inside and outside of protective structure. However, the higher ventilation rate may significantly raise the inside air temperature.

Sufficient light should be allowed to enter the structure which is essentially required by the plant for its growth and hardening of the plant stem.

Allow partial shading to the plants in the nursery.

Do thinning of the plants in nursery for improved aeration between the plants.

Treat the growing media for repeated use to prevent it from fungal diseases if any.

Temperature and relative humidity are two main parameters on which the performance of cucumber depends to a significant extent and should be maintained to optimum range.

The other factors such as level of CO_2, PAR and VPD may also be monitored and maintained to desired range if possible.

During warm climates, when temperature goes out of control even in the presence of a shade net at a certain height inside the structure, a shade net may also be installed outside the structure at desired location to reduce the unwanted radiation entering the structure. Doing this may significantly reduce the inside air temperature and maintain optimum microclimate.

The protected cultivation of cucumber in both open and closed soilless systems with efficient utilization of water and nutrients can support the sustainable vegetable production worldwide with no environmental pollution. The possibility of year round cultivation (thrice a year) of cucumber in soilless or hydroponic system under a protective structure may attract the growers to increase their productivity compared to cost of cultivation and making it as an economically feasible technique. Thus, in countries like India, with existing subsidies (given by state and central governments), the soilless cultivation of cucumber under protective structures may offer multiple benefits to the growers.

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