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Factors Affecting the Performance of Greenhouse Cucumber Cultivation-A Review

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ABSTRACT

Although, protective cultivation (in soil or soilless media) offers a favorable environment for crop growth, development and consequently, results in higher productivity. However, numerous factors viz. temperature, relative humidity, radiation, evapotranspiration (crop water requirement) vapour pressure deficit, plant stomatal conductance, irrigation, fertigation, disease incidence, leaf wetness duration, electricity cost, diesel fuel cost and labor cost affect the greenhouse cucumber production to a significant degree. In addition to the existing cost of protective cultivation, shifting from soil to soilless cultivation due to uncontrollable soil borne diseases has increased the cost of production significantly. Besides, the yield of crops including cucumber has significantly increased by shifting from soil to soilless growing media. Secondly, in developing countries, where the marginal farmers are uninformed and even cannot afford the initial investment, this technology is still a challenge to be adopted. On the other hand, the economic analysis of greenhouse cucumber production in a protective structure becomes important to compare the profitability of production with open field conditions. Overall, the yield and quality of vegetable production in different growing media under protective structures have shown a huge improvement which is not possible under open field conditions. Moreover, protective structures offer off-season cultivation of vegetables when offered with measures for controlling the microclimate. In other terms, to maintain an optimum microclimate inside a protective structure, artificial heating during winter or cooling during summer is required which increases the cost of production. Thus, to support the farmers, the government agencies should come forward to provide sufficient subsidy for installation of protective structures along with sophisticated instruments or the initial cost involved, particularly in the hilly regions where the conditions are favorable. Furthermore, the marginal farmer who cannot afford for sophisticated instruments should be aided with meteorological information from local government authority which may help him to plan the crop or maintain the desired environmental conditions accordingly. In the present study an attempt has been made to review the dynamic factors affecting performance of greenhouse cucumber cultivation.

Keywords

Cucumber, Benefit-cost ratio, Yield, Greenhouse, Microclimate.

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Introduction

Cucumber (*Cucumis sativus* L.) is one of the popular vegetable crops grown broadly throughout the world (Soleimani *et al.*, 2009).

Cucumber is a thermophilic and frost susceptible crop, growing best at a temperature above 20°C. Cucumber crop

grows successfully under conditions of high light, high humidity, high soil moisture, temperature and fertilizers in green-houses (El-Aidy *et al.*, 2007). Cucumber can be planted either by transplanting or direct seeding. The row to row spacing varies from 120 to 150 cm and plants to plants spacing varies from 30 to 45 cm. Cucumber is grown for its tender fruits, which are consumed either raw as salad, cooked as vegetable or pickled in its immature stage. Firmness is an important parameter of cucumber quality. Transpiration from the fruit, detached from the cucumber plant, considerably reduces its water content and therefore firmness. The dark green color on the surface of the cucumber is achieved by the presence of chlorophyll in the epidermis. The chlorophyll breakdown results in immediate degreening of cucumber fruit (Nobel 1991).

Moreover, exposure of cucumber plants to heat stress during fruit development stage causes bitterness of fruits. The calorific and nutritional value of cucumber is very low but it is a primary source of vitamins, minerals and fibre for human body (Keopraparl, 1997).

The protective cultivation supports a favorable environment to cultivate desirable crop year round. The area under protective cultivation has increased at a significant rate during past few couple of decades throughout the world. A greenhouse traps the short wavelength solar radiation to create a favorable microclimate for higher productivity (Tiwari, 2006). Carbon dioxide (CO₂) and photosynthetically active radiation (PAR) accumulated over the day, are the two primary variables which affect the plant growth in a greenhouse. Protected cultivation is now very much needed under Indian conditions to improve the productivity and quality of the vegetables (Kohli *et al.*, 2007). In the present scenario of perpetual demand of vegetables and shrinking land holdings

drastically, protected cultivation is the best alternative and drudgery-less approach for using land and other resources more efficiently. The practice of 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 because of mild climate (Mishra *et al.*, 2010). The cucumber yield in protected structures can be increased manifold as compared to than in open field cultivation. Moreover, production of cucumber in greenhouse or net house has led to the minimum use of chemical fertilizers and pesticides, which is not possible under open field conditions.

Solar radiation and ambient temperature are the main climatic parameters needed to evaluate the climate suitability in a region for protected cultivation. However, the temperature distribution in a greenhouse is one of the factors, which influence the uniformity of the crop growth (Sausser *et al.*, 1998). The other climate parameters such as soil temperature in relation to air temperature, wind, rainfall and air composition, influence to a lesser degree. However, the air temperature is only one of the parameters that strongly influence the crop growth. Water vapor pressure deficit (VPD) between greenhouse air and crop may affect the transpiration and consequently absolute air humidity.

The soil borne diseases have become a major limitation of protective cultivation (Fulya Baysal-Gurel *et al.*, 2012). The soilless cultivation is therefore, a possible alternative solution for sustainable protective cultivation. The soilless cultivation reduces the soil related problems experienced in the conventional crop cultivation. The yield of crops such as cucumber is significantly affected by different growing media. Moreover, the soilless materials viz. coco-

peat, rockwool are perlite are easier to handle and may provide a better growing environment compared to soil (Mastouri *et al.*, 2005). Soilless cultivation offers benefits such as capabilities to control water availability, pH and nutrient concentration in the root zone. Growing vegetable crops including cucumber in a media other than soil results in better control of plant nutrition and diseases (Olympious, 1995). Thus, an attempt has been made to review the dynamic factors affecting performance of greenhouse cucumber.

Greenhouse microclimate control

Greenhouse microclimate is the assemblage of climatological parameters forming around a living plant. It is imperative to monitor and maintain these parameters to optimum level for better crop growth and production. The greenhouse microclimate can be controlled by heating system, ventilation and fogging system, lighting and shading system, fertigation system and CO₂ injection system. Sufficient work has been recorded on controlling the microclimate inside a greenhouse and a few of them are listed here. Arellano *et al.*, (2006) evaluated the microclimatic condition inside two greenhouses of the Almeria type. Radojevic *et al.*, (2014) have described one practical approach to the real-time control system in a greenhouse.

Climatic factors

Temperature, relative humidity and radiation are the main climatic parameters which directly affect the cucumber growth thereby the yield to a significant level. The optimum temperature for cucumber growth as suggested by numerous researchers is presented in table 1. there are numerous indirect factors such as plant stomatal conductance, VPD and transpiration which

also strongly affect the cucumber productivity.

Irrigation, fertigation and water use efficiency (WUE)

Irrigation and fertigation scheduling of greenhouse cucumbers in soil and soilless media are quite different. Irrigation scheduling can be done by penman monteith method or PAN evaporation method. However, in soilless cultivation, there is a need for continuous supply of water and nutrients.

Water is an important limiting factor in the production and quality of cucumber because of its sparse root system. 85 % of the root length is concentrated in the upper 30 cm top of soil layer (Janoudi and Widders 1993; Wang and Zhang, 2004). Scheduling irrigation is very crucial, as excessive irrigation water reduces yield, while the inadequate supply causes water stress as well as yield reduction (Locascio and Smajstria, 1996). Greenhouse cucumbers grow quickly and have a high water requirement (Loomis and Crandall, 1977). At the early growth stages, the greenhouse cucumber grew very slowly, so the requirement for water is also low and the capacity of water uptake by roots is limited (Zotarelli *et al.*, 2009). Therefore, reducing water supply at seedling stage, controlling water supply at flowering stage and increasing water supply at fruiting stage of cucumber can increase yield and water use efficiency.

Numerous researchers have studied the effect of irrigation amount (Mao *et al.*, 2003) and fertilizer coupled irrigation (Ahmet *et al.*, 2006; Zhang *et al.*, 2011) on cucumber yield and water use efficiency (WUE). Mao *et al.*, (2003) have reported an increased WUE with increased level of irrigation water applied from fruiting to the end of the growth stage.

However, WUE increased with increase in irrigation water from cucumber fruit setting to the initial fruit repining stage. Therefore, the judicious use of the available water through more efficient methods of water application like drip irrigation under protected cultivation becomes necessary to enhance the yield and water use efficiency (Dunage *et al.*, 2009) and concluded that the application of moderate levels of urea containing nitrification inhibitor in greenhouse cucumber can achieve higher yields and water use efficiency (WUE).

Deficit irrigation

Deficit Irrigation (DI) is also one of the methods to save irrigation water and increase WUE (Kirda *et al.*, 2004), in which crops are deliberately exposed to some degree of deficit irrigation through either the whole growth stages or at certain stages of the growth period (Kirda *et al.*, 2004). DI involves supplying the root zone with less water than the maximum evapotranspiration (Zegbe-Dominguez *et al.*, 2003). Furthermore, DI is an optimization strategy in which irrigation is applied during non-drought, sensitive growth stages of a crop. After studying DI extensively on numerous crops (Pereira *et al.*, 2002, Kirda *et al.*, 2004), it has been recommended for arid and semiarid regions (Kirda *et al.*, 2004). However, the deficit water budgets lead to numerous physiological changes, such as altered root to shoot ratio, reduced leaf area or number of leaves, and finally reduced plant growth and yield.

The lack of rainfall or irrigation has been shown to reduce fruit yield and quality at a significant rate (Doss *et al.*, 1977; Elkner 1985). Amer *et al.*, (2009) concluded that cucumber yield significantly decreased linearly with increasing water deficit. However, no significant transform was observed when water was applied above 100% ET_c. Furthermore, Agele *et al.*, (2011)

concluded that the seasonal crop ET values are greater during reproduction growth stage of the crop. Wang *et al.*, (1999) studied the relationship between irrigation amount, yield and quality of cucumber under greenhouse. The drip irrigation with transparent mulch gave the highest soil temperature and moisture as compared to drip irrigation with black mulch. This enhanced the vegetative growth of cucumber and almost doubled its productivity compared to the surface furrow irrigation (SFI) (Yaghi *et al.*, 2013). According to Hakkim and Chand (2014), the total quantity of water applied through 65% drip irrigation level showed 35% water saving over control with highest WUE (6148.31 kg ha⁻¹cm⁻¹).

Alomran *et al.*, (2013) investigated a deficit irrigation system for its impact on soil salinity, crop response factor (K_y), crop water productivity (CWP) and yield of cucumber. The irrigation treatments consisted of four levels (40, 60, 80 and 100% of ET_c) in addition to the traditional practice by local farmers. The results showed that soil salinity in general increased with decreasing level of applied water. The water used in 100% of ET_c treatment was much lower than that in the traditional drip irrigation as practiced by farmers.

Yaghi *et al.*, (2013) compared the effect of two types of plastic mulch with drip irrigation on water requirement and yield of cucumber in addition to their effect on maturity time. Treatments included transparent mulched drip irrigation (DI + TM), black mulched drip irrigation (DI + BM), drip irrigation without mulching (DI) and surface furrow irrigation (SI). The study indicated that (DI + TM) treatment excelled all other treatments at yield and WUE, where its yield was 63.9 t ha⁻¹ and WUE was 0.262 t ha⁻¹mm⁻¹ while (DI + BM) treatment produced 57.9 t ha⁻¹ with a (WUE) of 0.238 t ha⁻¹mm⁻¹. Hakkim and Chand

(2014) studied the yield response of salad cucumber under differential drip irrigation scenarios to determine the most suitable irrigation requirement for salad cucumber grown under naturally ventilated polyhouse. Huber *et al.*, (2005) confirmed that irrigation is extremely important for crop production. Medrano *et al.*, (2005) calibrated the coefficients of the simplified Penman-Monteith formula to calculate the transpiration rate of the crop to improve irrigation management in substrate cultivation and concluded that the fitted simplified Penman-Monteith formula could be used to predict water requirements of crops under Mediterranean conditions and improve irrigation control in a substrate culture. However, the model coefficients will have to be adjusted for specific climate and crop conditions. Protective cultivation may reduce water and nutrient consumption by 22% and 35% respectively in cucumber production (Tuzel *et al.*, 1999). Moreover, a closed substrate culture is more efficient with the use of water and fertilizers, and cause less damage to the environment.

Crop water requirement (crop ET or transpiration)

Understanding evapotranspiration or simply transpiration for greenhouse crops and development of a mathematical model for predicting evapotranspiration can be a valuable tool in design of greenhouse-ventilation and irrigation system. Many studies have attempted to model plant transpiration including Stanghellini (1987) and Yang (1988). The knowledge of crop transpiration over time may also serve to improve irrigation control in soilless culture, since an accurate and dynamic control of the water supply is needed to meet water requirements of plants, due to the low water-holding capacity and limited volume of certain substrates (De Boodt and Verdonck,

1972). Medrano *et al.*, (2005) modeled and evaluated the transpiration time course of soilless cucumber plants during two cycles at low (up to $9 \text{ MJ m}^{-2} \text{ d}^{-1}$) and high (up to $20 \text{ MJ m}^{-2} \text{ d}^{-1}$) radiation levels, and their relationship with greenhouse climatic parameters and canopy development.

The key factors affecting greenhouse crop transpiration are solar radiation, vapour pressure deficit, canopy and aerodynamic conductance. According to Yang *et al.*, (1989), a very low relative humidities of the greenhouse air during daytime and unlimited water supply are important factors in achieving high transpiration rates.

The greenhouse limits water-vapour exchange with the outside air, producing a feedback effect, since a change in crop transpiration alters the water-vapour content in the greenhouse air that affects the transpiration rate (Aubinet *et al.*, 1989). Boulard and Wang (2000) presented a new and simple greenhouse crop transpiration model enabling predictions from outdoor conditions for tomato crop cultivation in summer conditions, when the greenhouse was open, and early spring climatic conditions, when the greenhouse was kept closed and the inside air strongly confined. Cucumber crop transpiration can be estimated using the formula derived from the Penman-Monteith equation (Baille *et al.*, 1994). Yang *et al.*, (1990) found that the temperature difference between the top and bottom cucumber leaves was small and Boulard *et al.*, (1991) found that both single and a multi-layer models gave similar results for canopy transpiration. Some researchers have, therefore, estimated the leaf temperature by the transpiration model (Stanghellini, 1987; Jolliet and Bailey, 1994) and by the leaf energy balance model (Papadakis *et al.*, 1994). Crop evapotranspiration can also be effectively modeled using the Penman-Monteith equation

(Sumner and Jacobs, 2005). However, Zi-kun *et al.*, (2010) concluded that the Pan evaporation (E_p) gives better estimate of daily cucumber evapotranspiration than the reference evapotranspiration (ET_o) calculated from Penman-Monteith model. Most recently, Alomran *et al.*, (2013) observed a good agreement between Pan Evaporation method and Penman-Monteith equation for calculating crop ET for both greenhouse and open field conditions. Hashem *et al.*, (2011) reported the highest vegetative growth at 100% of ET_o compared to 80% and 120% of ET_o treatments.

Several authors indicated that the greenhouse shading causes a decrease in crop temperature and transpiration rate (Boulard *et al.*, 1991, Dayan *et al.*, 2000). Boulard and Baille (1993) observed that transpiration is significantly affected by the air exchange rate and the air vapour pressure deficit. Transpiration is the most important part of the latent energy and one of the most important elements of greenhouse energy balance. Yang *et al.*, (1990) observed a strong correlation between crop transpiration and solar radiation for cucumber crop.

Transpiration in relation to VPD and plant stomatal conductance

Stomatal conductance and vapour pressure deficit (VPD) are two key parameters which affect the crop transpiration both in soil and soilless media to a great extent. The stomatal conductance plays an important role in the division of energy into sensible and latent heat and is affected by a number of microclimate parameters such as VPD, air temperature and CO_2 concentration in the air, and the leaf water potential (Choudhury and Idso, 1985; Grantz and Zeiger, 1986). Montero *et al.*, (2001) observed no significant reduction of crop stomatal conduction when air vapour pressure deficit increased from 1.4

kPa to 3.4 kPa. However, use of fog cooling increased crop stomatal conductance and indicated maximum crop stomatal conductance when solar radiation exceeded 300 W m^{-2} in Mediterranean greenhouses (Baille *et al.*, 1994a; Katsoulas *et al.*, 2001). According to Bakker (1991), under high light intensity and at ambient CO_2 concentration ($350\text{ }\mu\text{mol mol}^{-1}$), cucumber has been found to have a stomatal resistance of 50 s m^{-1} . Yu *et al.*, (1999) have noticed that the stomatal resistance of fig leaf gourd was not affected until the root temperature was lowered to 8°C while it decreased significantly in cold-sensitive cucumber rootstocks.

Many researchers (Kaufman, 1982, Munro, 1989, Baille *et al.*, 1994a) studied the effect of air VPD on crop stomatal conductance. For the same increase in air VPD, total crop conductance decreased from 1.6 to 3 times more at wind speed of 3 m s^{-1} than at 0.5 m s^{-1} (Bunce, 1985). For short periods, when the air vapour pressure deficit increases, stomata begin to shut down gradually to reduce water stress (Choudhury and Monteith, 1986). Kittas *et al.*, (2001) observed that increasing greenhouse air exchange rate by means of forced ventilation resulted in an increase of canopy to air VPD with a decrease of crop stomatal conductance by 20% compared to natural ventilation.

Disease incidence

The uninterrupted cultivation under greenhouses conditions have contributed towards the high incidences of soil-borne diseases. Cucumber is attacked by several fungi, bacteria, viruses and nematodes. Sharma *et al.*, (2007) have reported severe nematode infestation in cucumber as compared to sweet pepper. Root-knot nematodes (RKN) infect roots and cause the production of root galls also known as giant cells. Plants experience a reduced flow of

water and nutrients, and subsequently, reduced vegetative growth and yield. RKN jeopardize the soil-grown greenhouse crops (Raspudic *et al.*, 2006) and may result in cucumber yield losses of approximately 12% (Main and Gurtz, 1989). In recent past, Kayani *et al.*, (2013) have also given a clear indication of severe infestation of RKN in cucumber, demanding adoption of strict measures for its management.

Leaf wetness duration (LWD)

LWD is also one of the most critical parameters involved in the development of plant diseases, seeing as many pathogens require the presence of free water on plant organs to infect foliar tissue (Huber and Gillespie, 1992; Kim *et al.*, 2004). Dew appears on leaves when the leaf temperature is less than or equal to the dew point (Yunis *et al.*, 1990). But, because of the difficulty in obtaining accurate leaf temperature data, the majority of researchers instead try to use other parameters such as relative humidity, wind speed, minimum temperature, dew point depression to estimate the LWD empirically (Gillespie and Barr, 1984; Huber and Gillespie, 1992; Gleason *et al.*, 1994). Thus, LWD monitoring is extremely important in crop protection, particularly through the use of weather-related disease forecasting models which are frequently used as alternatives to field measurement of LWD (Marta *et al.*, 2005; Sentelhas *et al.*, 2007).

In a relatively dry winter when leaf wetness was the limiting factor for disease development, a positive correlation was found between dew period and incidence of cucumber gray mold (Elad *et al.*, 1989). On the other hand, the time periods with temperatures in the range of 15-25°C were correlated with disease incidence in an abnormally wet winter (Elad *et al.*, 1989). Later on, Yunis *et al.*, (1990) concluded that

the humidity and leaf wetness influence the disease less than does temperature in the optimum range.

According to Zhang *et al.*, (1997), when local weather forecasts are available, a model can be applied to forecast microclimate parameters and leaf wetness duration in greenhouses. Such information would be valuable for predicting occurrence of certain climate-related diseases and can be used by growers to help them decide on the optimal precautions to take to prevent possible epidemics (Zhang *et al.*, 1997). Presently LWD is used as an input in many disease forecast models and warning systems in greenhouse crop production including cucumber (Huber and Gillespie, 1992; Korner and Holst, 2003; Zhao *et al.*, 2011; Baptista *et al.*, 2012; Mashonjowa *et al.*, 2013).

Control of soil borne diseases

In order to develop a reliable and effective early warning system, it is obligatory to understand the information concerning epidemiology of pathogens, greenhouse microclimate, cucumber growth and agronomic practices (Jeger, 2004). Fumigation is the most effective approach to control soil borne pests (e.g. nematodes, parasitic plants and weeds). Moreover, mixing chicken manure or dry cabbage leaves in the soil before mulching can control the RKN (Gamliel and Stapleton, 1997). Most recently, Abdel-Kader *et al.*, (2015) have recommended pesticide alternatives for controlling root-rot fungus and root-knot nematodes of cucumber under plastic house conditions for wider applications since they introduced efficient disease control and increased yield of cucumber.

Grafting of vegetable is another approach to improve yield, fruit quality and disease resistance in Solanaceae and Cucurbitaceae

(Lee *et al.*, 2010; Schwarz *et al.*, 2010). The commonly used methods for grafting are splice or tube, tongue and cleft (Khankahdani *et al.*, 2012). According to Schwarz *et al.*, (2010), about 50% reduction of aldrin pollution in cucumber is possible using a low-uptake rootstock similar to Yuyuikki-black. Marsic and Jakse (2010) observed that the grafted plants formed a significantly larger stems and longer root systems which increased the yield of cucumber to 24% on different soilless substrates. Consequently, Reid and Klotzbach (2011) have also reported that the grafting of cucumber results in yield increments. Most recently, Farhadi *et al.*, (2016) have studied the effectiveness of different rootstocks for improving yield and growth of cucumber cultivated hydroponically in a greenhouse and reported that cucumber production is not improved by grafting.

Soilless cultivation

Nowadays when cucumber cultivation in soil under both open field conditions and protective structures has become impossible due to soil borne diseases, soilless cultivation has become an alternative. Enough work has been carried out to cultivate cucumber in soilless culture under protective structures.

Huber *et al.*, (2005) cultivated cucumbers in a specifically designed urethane based recyclable plant growth substrate (UBS) and rockwool (RW) under a recirculating hydroponic production system to evaluate the performance of UBS in a greenhouse hydroponic production system and compare the effectiveness of two irrigation schedules on cucumber production using UBS. Medrano *et al.*, (2005) also cultivated cucumbers in soilless culture. Al-Mulla *et al.*, (2008) evaluated the effects of screenhouse microclimate on cucumber grown on hydroponics. Two types of substrate growing

systems viz. Wood Straw (WS) and Date Palm Straw (DS) were evaluated. Cucumbers planted in WS gave significantly higher number of produced fruits per plant than those planted in DS system.

Nutrients management

Fertigation in both soil and soilless media can be done through using water soluble fertilizers along with irrigation water thereby enhancing the fertilizers use efficiency. However, the cucumbers production in soilless media requires a continuous supply of nutrient solution which is not required while grown in soil.

The nutrient solution contains the essential macro and micronutrients. The primary macronutrients includes N, P and K, while the secondary macronutrients includes Ca, Mg and S. However, the micronutrients includes B, Fe, Mn, Cu, Zn and Mo. Nutrient solution can be prepared according to Papadopoulos (1997).

Measurement of pH and EC of nutrient solution

The measurement of chemical properties viz. pH and electrical conductivity (EC) of nutrient solution and soilless media can be done using a digital waterproof tester. The pH and EC values determine the nutrient availability for plants uptake. Thus, pH and EC adjustment must be done on daily basis to the lower buffering capacity of soilless culture using chemicals such as phosphoric acid to lower pH and potassium hydroxide to raise pH.

Cucumber is considered as moderately sensitive to salinity having threshold EC value of 3.0 dS m⁻¹ among the vegetable crops. Mulching with polyethylene or polypropylene sheet is an alternative to control of EC.

Yield of cucumber

The cucumber yield under protective cultivation can be increased manifold as compared to than in open field cultivation. According to Spehia (2015), the productivity of cucumber inside polyhouses was more than four times as compared to open field cultivation. Yield of cucumber is mainly determined by the accumulation of fresh weight of the harvested fruit and the fresh weight is closely related to dry weight (Heuvelink and Marcelis, 1989). Hashem *et al.*, (2011) found that the cucumber growth indicator such as plant height, total leaf area, total fresh weight, total dry weight and fruit yield were increased by using white net cover throughout the growing season. According to Selivanova *et al.*, (2015), the enhanced metabolism of the cucumber plants resulted in increase of yields. The highest yield of cucumber exceeding the control by 14.7% was obtained at combined use of growth factors, namely Radifarm, Benefit and Megafol. Lorenzo *et al.*, (2006) observed an increased yield of cucumber under shading, reduced crop transpiration and thus water uptake with improved water use efficiency by 62% for cucumber crop.

Sonneveld and Voogt (1978) obtained cucumber yields of 27.0 kg/m² for the spring crop and 12.0 kg/m² for the fall crop. In general, the cucumber fruit having diameter just above 2.54 cm is ready for picking in its immature stage. However, at maturity, the cucumber fruit is usually 30 to 35 cm long and 4 cm in diameter. The fruit has a very high water content of 95.5% (Sutherland, 1988).

Pettersen *et al.*, (2010) concluded that cucumbers need a daily dark period to achieve optimal growth. In the lower part of the canopy, poor light conditions result in reduced photosynthetic capacity in a major

part of the total leaf area. Cultivation methods that can allow more light to reach the lower canopy, might have the potential to increase yield in crops including cucumber. However, applying supplementary lighting at a continuous rate to avoid a temperature drop due to low outside temperature in winter has been reported to have harmful effects in cucumber crops. If continued for a duration of more than one week, reduced fruit yield and leaf photosynthesis has been observed (Wolff and Langerud, 2006). Zhang *et al.*, (2011) reported that nitrogen fertilizer input had a significant effect on the cucumber yield showing yield increment from 21,240 kg ha⁻¹ to 49,730 kg ha⁻¹ with a nitrogen input from 300 kg ha⁻¹ to 600 kg ha⁻¹. Tazuke and Sakiyama (1986) have related cucumber growth rate linearly to the increased fruit temperature. Nederhoff (1987) estimated the optimal CO₂ concentration from the radiation, wind speed and window aperture, which resulted in a significant decrease of CO₂ consumption, compared to a constant set point but resulted in a comparable cucumber yield.

Liebig (1980) predicted the time until 1 kg of fruits was produced, based on mean temperature and mean global radiation for a young cucumber crop. Subsequently, Liebig and Krug (1990) related yield directly to week of the year.

According to Olympious (1995), growing vegetable crops including cucumber in a media other than soil results in better control of plant nutrition and diseases. Ghehsareh *et al.*, (2012) obtained higher cucumber yield, biomass weight, plant height, root weight, leaf area index (LAI) and fruit total soluble solids (TSS) on using date-palm leaves as media compared to the conventional soil system.

Most recently, while studying the effect of different growing media on cucumber production and water productivity in soilless

culture under UAE conditions, Mazahreh *et al.*, (2015) indicated that by mixing coco-peat with perlite in 1:1 ratio, the yield increased significantly by 82% compared to cocopeat growbags. Mazahreh *et al.*, (2015) have obtained highest and lowest yield of 87.6 t

ha⁻¹ and 46 t ha⁻¹ grown under perlite:coco-peat (1:0) and coco-peat grow bag respectively. The yield was significant increased by 82% by mixing coco-peat with perlite in 1:1 ratio, compare to coco-peat grow bags.

Table.1 The suggested optimum temperature for cucumber growth by different researchers

	Day	Night	Minimum night	
Greenhouse air temperature	23.9-26.7°C	21.1-23.9 °C	18.3 °C	Johnson and Hickman 1984
	28.0 °C	≥18 °C	19.0 °C (22.0-33.0°C is preferable)	Haifa* –Pioneering the future
	22.0-24.0 °C	-	21.0 °C	Johnnys selected seeds-An employee-owned company (2016). Greenhouse cucumber production
	30.0 °C	20.0 °C	-	Hui <i>et al.</i> , 2003
Min Root zone temp	10.0-12.0 °C			Slokangas 1973

*Haifa –Pioneering the future: Nutritional recommendations for cucumbers in open fields, tunnels and greenhouse. Relative humidity which is inversely related to air temperature inside the greenhouse also affects the crop growth.

Economic constraints

It includes fixed cost and variable cost involved in crop production. Fixed cost includes cost of protective structure, cost of irrigation coupled fertigation system and cost of plant support system in the case of soilless system (growing media, roller hooks, nylon thread) required. Variable cost includes the cost involved in electricity use, diesel fuel (if any), fertilizer, labor, irrigation (if any) etc. Total cost equals to sum of fixed cost and variable cost

Energy consumption

The fuel and electricity are two major energy inputs for greenhouse cucumber production.

Ozkan *et al.*, (2004) reported a total of 134,771.3 MJ ha⁻¹ as energy input for greenhouse cucumber production of any one period of plant cultivation. According to Monjezi *et al.*, (2011), the quantity of input energy required gets reduced by keeping the cucumber yield at fixed level.

Taki *et al.*, (2012) observed that that the cucumber production consumed a total of 124447.5MJ ha⁻¹ and diesel fuel was the major energy input. According to Pahlavan *et al.*, (2012), the total input and output energy for greenhouse cucumber were 436,824 MJ ha⁻¹ and 128,532 MJ ha⁻¹ respectively.

Firoozi *et al.*, (2014b) have reported that a total operational energy of 521.37GJ ha⁻¹ was

consumed in greenhouse cucumber production. The shares of this energy were fuel (56.66%) and chemicals (12.19 percent). However, Sami and Reyhani (2015) reported that the diesel fuel and electricity were the biggest energy consumers in the farms with shares of 59.31 and 25.58% of total input energy. Most recently, Sami and Reyhani (2015) have reported an average annual crop yield of the greenhouse cucumber of 89868.54 kg/ha which demanded an average energy input of 699217.04 MJ/ha. While holding the constant output level of cucumber yield, Taki *et al.*, (2012) concluded that about 10105.14 MJ ha⁻¹ of total input energy could be saved. Moreover, Firoozi *et al.*, (2014a) concluded that 182.21 GJ ha⁻¹ of total input energy could be saved and Firoozi *et al.*, (2014b) concluded that 140 GJ ha⁻¹ of total input energy could be saved.

Economic analysis

The economic analysis of greenhouse cucumber production is important in order to compare profitability of production in comparison with the open field conditions. Growing cucumbers under greenhouse conditions is more profitable as compared to open field conditions as reported by various authors in the past.

Engindeniz and Guel (2009) conducted a study on economic analysis of greenhouse cucumbers based on growing cucumbers in a mixture of perlite and zeolite, and the growing of cucumbers in the ordinary soil.

Pozderek *et al.*, (2010) developed a technological-economic simulation models for growing cucumbers including pepper outside and inside protected space which can be used to calculate the important economic parameters. Results from the study conducted by Duan *et al.*, (2011) has indicated that the biogas fertilizer can effectively reduce

diseases and pests, bring good economic, social and environmental benefits, and promote the low-carbon circular development of crop farming.

Hassanpour *et al.*, (2013) conducted a study to examine factors affecting the marketing margin of greenhouse cucumbers and tomatoes in order to develop an approach for solving problems and to expand the market of these agricultural products. Their study revealed that the unawareness of market conditions, lack of facilities and shortage of underlying facilities were the most important problems for producers of greenhouse cucumbers and tomatoes. While studying the economic and agronomic analysis of conventional and organic concept of cucumber growing,

Pavlovic *et al.*, (2014) recorded financial losses on growing cucumbers in the open field despite lower costs, both in organic and conventional system of growing. The business rate of profitability and the coefficient of cost-effectiveness were higher in growing cucumber in greenhouses in both concepts of production. The economics of greenhouse production is generally expressed in terms of

$$\text{benefit - cost ratio (BCR)} = \frac{\text{Benefit}}{\text{Cost}}.$$

Where, $BCR > 1$ is acceptable while $BCR < 1$ is not acceptable. Hakkim and Chand (2014), has mentioned a benefit cost (BC) ratio of 3.41 in cucumber production in a naturally ventilated greenhouse.

Most recently, Kumar *et al.*, (2015) have reported that the cost of cucumber cultivation under playhouses was comparatively higher (7088 USD/ha) compared to open field conditions (3708 USD/ha).

Conclusions and suggestions

The greenhouse technology offers a favorable environment for cucumber growth and production, and consequently results in a significant yield increment may be due to enhanced metabolism of cucumber plants, greenhouse shading, cultivation methods, fertilizers application and CO₂ level in the greenhouse. Irrespective of the factors affecting the cucumber growth, the yield under protective cultivation can be increased manifold as compared to than in open field cultivation as reported by numerous authors in past.

At present, cultivation of vegetable crops particularly, cucumber in soil has become impossible due to occurrence of soil borne diseases. The soilless cultivation is therefore a possible alternative for protective cultivation of cucumber due to its better control on diseases and allows uniform application of water and nutrient directly to the plant root system.

The yield of crops including cucumber has significantly increased by shifting from soil to soilless growing media such as coco-peat, rockwool and perlite. The economic analysis of greenhouse cucumber production in a protective structure is important to compare the profitability of production with open field conditions.

Overall, the yield and quality of vegetable production in different growing media under protective structures have shown a huge improvement which is not possible under open field conditions. Moreover, protective structures offer off-season cultivation of vegetables when offered with measures for controlling the microclimate.

Judicious use of the available water through more efficient methods of water application

like drip irrigation under protected cultivation becomes necessary to enhance the yield and water use efficiency. The drip irrigation system is better than other conventional irrigation methods, as it can be used to control crop growth by regulating the supply of water and nutrients.

Reducing water supply at seedling stage, controlling water supply at flowering stage and increasing water supply at fruiting stage of cucumber can increase yield and water use efficiency.

The knowledge of crop transpiration over time may also serve to improve irrigation control in soilless culture, since an accurate and dynamic control of the water supply is needed to meet water requirements of plants, due to the low water-holding capacity and limited volume of certain substrates

For cucumber cultivation in soilless media, monitoring and adjustment of pH and EC of nutrient solution should be done on regular basis since these parameters regulate the nutrients uptake by plants.

For monitoring and control of microclimate, modeling is also an efficient method for predicting the greenhouse microclimate under different outside climatic conditions. Predicting microclimate inside a greenhouse can help growers to manage crop production and designers to improve the ventilation and heating systems.

The government agencies should come forward to provide sufficient subsidy for installation of protective structures or the initial cost involved particularly in the hilly regions of the country. There should have precision instrumentation for monitoring and regulation of greenhouse microclimate for optimal crop production. For a marginal farmer who cannot afford for instrumentation

part, should be aided with meteorological information from local government authority which may help him to plan the crop or maintain the desired environmental conditions accordingly.

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