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Research Paper

Response of horticultural crops under variable microclimatic conditions of different protected cultivation structures

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Abstract : Protected cultivation structures provide favorable environment for crop growth thereby achieving greater yield and high quality produce. The objective of this work was to evaluate the microclimate parameters such as temperature, relative humidity, solar radiation and light intensity underdifferent protected cultivation structures in comparison with open field condition. Four types of protected cultivation structures (polyhouse, walking tunnel,shadenet house and modified greenhouse) were considered for the study. Meteorological data of seven years (2010-2016), recorded on daily basis were used for micro climate analysis of different protected cultivation structures. FAO-56 Penman Monteith approach was used to estimate the reference crop evapotranspiration under different kind of protected cultivation structures.Study shows that walking tunnel, polyhouse and modified greenhouse structures offers a solar energy saver and enhances temperature inside the structures. The total water requirement of drip irrigated crops in protected cultivation structure is reduced by about 25% to 35% under different protected cultivation structures in comparison to open field cultivation. This paper also presents the difference incrop yield grown under protected cultivation structures and open field condition.

Key Words : Temperature, Relative humidity, Polyhouse, Shadenethouse, Walking tunnels

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Introduction

After the advent of green revolution, more emphasis is laid on the quality of the produce along with the quantity of production to meet the ever growing food requirements. Both of these requirements can be met when the environment for the plant growth is suitably controlled. The need to protect the crops against unfavorable environmental conditions led to the development of protected agriculture. Protected cultivation makes it possible to obtain increased crop productivity maintaining a favorable environment for the plants. Therefore, production in protected cultivation structures (PCS) has become more popular than in the past. Protected cultivation structures are the most practical method of achieving the objectives of protected agriculture, where the natural environment is modified by using sound engineering principles to achieve optimum plant growth and yields. The design and creation of acontrolled environment in protected cultivation structures depend upon the climatic conditions of a place and plants requirement. Protected cultivation structures permitto cultivate four to five crops in a year with controlled microclimate, efficient use of various inputs like water, fertilizer and seeds and plant protection chemicals. In addition, automation of irrigation, precise application of other inputs and environmental controls by using computers and artificial intelligence is possible for the acclimatization of tissue culture plants and high value crops in PCS.

The inside environment (microclimate) of a PCS is controlled by factors such as light, temperature, humidity and carbon dioxide concentration. The effects of PCS environment on growth, development and productivity of crops have been studied by many researchers. Crop yield mainly depend on the responses of plants to environmental influences (Ellis *et al*., 1990) for example, temperature has considerable influence on crop timing and yield (Pearson *et al*.,1995) and light is primary determinant of crop growth. Micro climate of PCS can be scientifically controlled to an optimum level throughout the cultivation period, to increase the productivity by several folds.

There is a need to assess the cultivation and suitability of different horticultural crops under protected cultivation structures. Thus, the investigation is aimed to determine the influence ofPCS on micro climatic parameters. In this research manuscript an attempt is made to assess effect of micro climatic parameters obtained under PCS onthe crop water requirement of horticultural crops grown in sub-humid and sub-tropical climate of Odisha.

MATERIAL AND METHODS

The study area is located at experimental farm of Smart Agriculture Research Centre, Centurion University of Technology and Management (CUTM) Paralakhemundi, The experimental farm is located on the flat land at18°47’ N latitude, 84°06’ E longitude and altitude of 116 m above mean sea level.Experimental field soil is characterized as red lateritic with sandy loam in texture. The Paralakhemundi climate is classified as subtropical with high humidity. The temperature varies between 18°C-48 °C. It is characterized as hot and humid in summer (April and May), rainy season during June to September, moderately hot and dry inautumn (October and November), cool and dry in winter (December and January) and moderate spring in February and March. The average climatic data *i.e.* rainfall, maximum and minimum temperature, relative humidity and wind speed were collected Meteorological Department, CUTM, Paralakhemundi.

Four types of PCS (polyhouse, walking tunnel, shadenet house with 75% shade and modified greenhouse with 75% shadenet and 200 micron UV stabilized film) were considered for the study. The width of all structures is 5 m, the length is 20 m. Heights are 4.5 m, 3 m, 4.5 m and 4.5 m for polyhouse, walking tunnel, shadenet house and modified greenhouse (MGH), respectively.

The meteorological data on significant weather parameter during the crop growth period were collected on daily basis from the Meteorological Department, CUTM, Paralakhemundi. Automatic weather station of M/S Campbell Scientific, Canada comprising a data logger (model CR1000) and sensors were installed in the PCS to monitor soil temperatures (models 107 BL and CS616 L), air temperatures and relative humidity (model HMP 45C), global radiation and photosynthetically Active Radiation (SPLITE and PARLITE of Kipp and Zonen). Outside air and soil temperatures, relative humidityand solar radiation were measured manually at 8:30 AM, 12:30 PM and 4:00 PM in a day.

The daily irrigation water requirement for the crops were estimated by using the following relationship.

WR = ETo x Kc x Wp x A

where,

WR = Crop water requirement (L d^{-1});

ETo = Reference evapotranspiration (mm d^{-1})

Kc = Crop co-efficient ;

Wp = Wetting fraction

A = Plant area, m^2 (*i.e.* spacing between rows, m x spacing between plants, m).

The daily meteorological data recorded during the year 2010to 2016 were used to compute reference evapotranspiration (ET_0). These data include maximum and minimum temperature, minimum and maximum relative humidity, solar radiation and daily wind speed etc. The daily reference evapotranspiration (ET_0) was estimated by using FAO Penman-Monteith (Allen *et al.*, 1998) equation.

RESULTS AND DISCUSSION

The presence of cover, characteristics of protected cultivation structures, causes changes in the climatic conditions compared to those of outside for all the seasons. Radiation and air velocity are reduced, temperature and water vapour pressure of the air increases. Each of these changes has its own impact on the growth, production and quality of the crop inside the protected cultivation structures (Singh and Sirohi, 2006).

Micro climate parameters ofdifferent PCS :

Temperature :

Temperature has a direct impact on the physiological development phases (flowering, germination, development) of the plant. Itregulates transpiration rate and plant water status through stomatal control during the photosynthesis. Each crop and its development process respond differently to temperature. The difference between day and night temperatures as well asthe average 24 hour temperatures can also affect plant growth. Temperature of climate of an areaplays an important role in designing structures and control systems.

Variations of maximum and minimum temperature in different PCS were recorded on daily basis and are presented as monthly average in Fig. 1. Air temperature recorded in these structures showed that the use of different covering materials for structure exerted an influence on temperature. Average monthly maximal and minimal air temperature values recorded for open field were higher (upto 3^0C) for different months compare to values recorded for shadenet structure. Air temperatures tended to be lower under the shade net comparing with the open field and other covers, due to the interception of radiation which is greater than the gain of temperature caused by the use of shadenet. Shade nets also reduce wind speeds and wind run (Stamps, 1994), which can

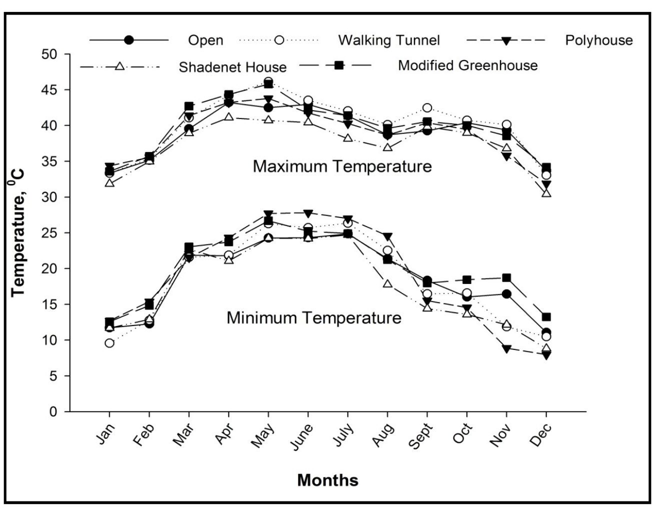

Fig. 1: Monthly average of daily maximum and minimum temperatures recorded in different PCS and open field condition

affect temperatures.

However, maximum and minimum temperature values of open field were lower upto 4^0C, 2^0C and 3^0C compare to the values recorded for walking tunnel, polyhouse, modified greenhouse, respectively during summer and monsoon months. During winter months (December to March) higher value of maximum and minimum temperature recorded in modified greenhouse compare to other PCS and open field conditions. Interception of air within the structure daily maximum and minimum temperature tended to be higher in case of walking tunnel followed by Poly house and modified greenhouse.

Higher values of maximum and minimum temperature were recorded inside the walking tunnel structure during summer and monsoon months (April to November) compare to other PCS and open field condition. Poly film increases the temperature by accumulation of solar radiation inside structures and shade net reduces temperatures inside a structure by reducing the amount of solar energy that enters structures (Pérez *et al.,* 2006 and Santosh *et al.*, 2017). Temperature variation inside polyhouse and modified greenhouse showed that the use of polyethylene exerted an influence on temperature. Interception of air within the structure increases the daily maximum and minimum temperature compare to outside environment. Except winter months (November to February), polyhouse and modified greenhouse recorded the equal or higher value for maximum or minimal air temperatures compare to open condition. Ganesan (1999) reported that the mean monthly temperatures during January to October were found to be higher by 2^0C inside the greenhouse than in the open field. Higher temperature during daytime was due to trapping of short wave radiation in the greenhouse under partially closed conditions. Nimje and Shyam (1993) also obtained similar results.

Relative hyumidity :

Relative humidity (RH) is the amount of water vapor content in the air. Maintaining the RH above some minimum value helps to ensureadequate transpiration and also reduces disease problems. Relative humidity within the range 60-90 % is suitable to plant growth. Fig. 2 shows that the monthly average of daily RH is significantly lower for open field compare to monthly average value of daily RH inside all PCS. Relative humidity increased in walking tunnels by 19–25% as compared with open field which is followed by polyhouse (17-23%), modified greenhouse (15-21%) and shadenet house (10-17%). These results were in line with those reported by Igle-sias and Alegre (2006), indicating a 9–13% increase in humidity associated with the use of shade nets. These researchers also reported a decrease in evaporation associated with the use of cladding materials and a significant reduction in wind speed. However, Nimje and Shyam (1993) observed that the relative humidity was higher inside the greenhouse than in the open field condition.

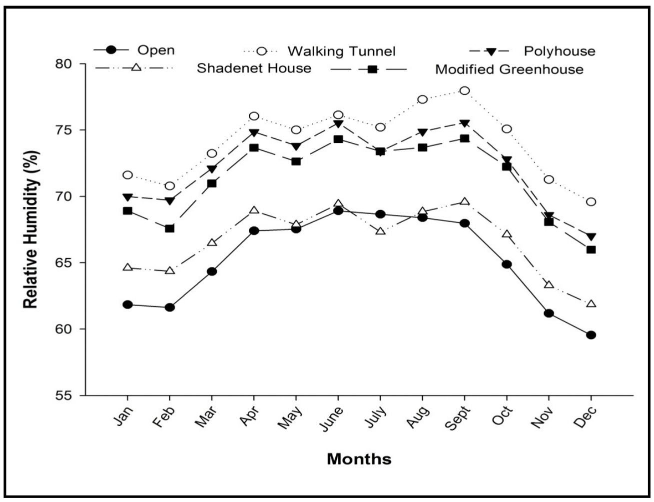

Fig. 2: Monthly average of daily mean relative humidity (%) recorded in different PCS and open field condition

Solar radiation :

Most important for photosynthesis in plants is solar radiation power (W/m^2). The production of plant drymatter decreases almost linearly with the radiation atlow solar radiation values. Monthly average of daily net solar radiation measured inside different PCS and open field condition are presented in Fig. 3. The poly film transmits solar radiations about 60 to 80% depending upon the intensity and sunshine hours. During winter months (November to February) difference in net solar radiation between inside PCS and open field was less compare to summer and monsoon months (March to October). The cladding materials covering on PCS significantly changes the radiation balance relatively to the external environment, because of the attenuation (absorption and reflexion) of the incident solar radiation, resulting in a reduction of the internal radiation balance (Sentelhas, 2001). Fig. 3 also shows that among all PCS, maximum solar radiations transmitted insides hadenethouse (74% to 85%) followed by walking tunnel (71% to 81%), polyhouse (60% to 78%) and modified greenhouse (60% to 73%). Due to the fact that modified greenhouse has both polyfilm and shadnet, which reduces the transmittance of solar radiation compare to other PCS.

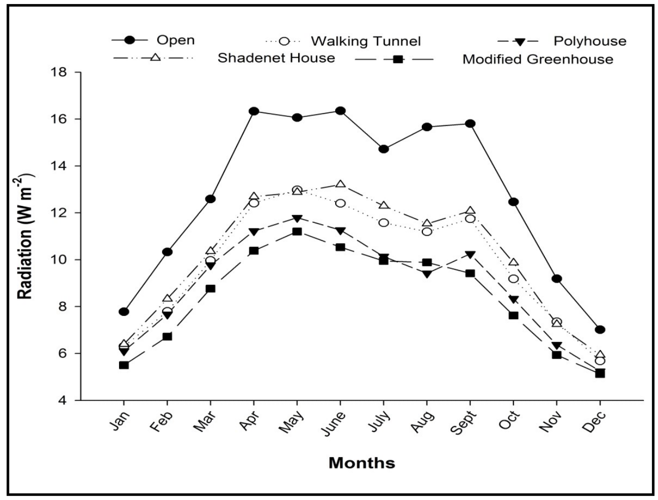

Fig. 3: Monthly average of daily net solar radiation (W m^{-2}) recorded in different PCS and open field condition

Light intensity:

The growth of plants is controlled by three light (photo) processes, namely photosynthesis, photomorphogenesis and photoperiodism. Every variation in light has a direct effect onthese processes. Light is part of the photosynthesis process, by converting carbon dioxide into organic material and then releasing oxygen in the presence of light. Greenhouse crops are subjected to light intensities varying from 129.6 klux on clear summer days to 3.2 klux on cloudy winter days. For most crops, neither condition is ideal. Many crops become light saturated, in other words, photosynthesis does not increase at light intensities higher than 32.2 klux. Light intensity (lux) inside PCS is significantly low in case of modified greenhouse (20.4 to 35.7 klux) followed by shadenet house (27.5 to 45.6 klux), polyhouse (41.6 to 60.7 klux) and walking tunnel (50 to 65 klux) compare to open field condition (more than 120 klux). Kaname and Itagi (1973) also found similar results for tomato cultivation under protected cultivation.

Soil temperature :

Soil under walking tunnel, polyhouse and modified greenhouse always maintained a 2-3^{0}C higher soil temperature as compared to temperature at outside soil irrespective of growing periods of the crop. Increase in soil temperature by 1 to 3^{0}C inside greenhouse was reported by Parvej *et al*. (2008). Mineral uptake is generally increased by a rise in soil temperature. Increasing soil temperature accelerated the growth of young vegetable plants and improved fruit colour as reported by Al-Kayssi *et al*. (1990).

Reference evapotranspiration :

FAO-56 Modified Penman–Monteith (PM) equation was used for estimating reference crop evapotranspiration, the microclimate data plays an important role in irrigation planning. With the appropriate climatic data measured in the greenhouse, crop water requirement was predicted using the evapotranspiration equation from PM model. The cladding materials covering on protected cultivation structures, significantly changes the radiation balance relatively to the external environment, because of the attenuation (absorption and reflexion) of the incident solar radiation, resulting in a reduction of the internal radiation balance and consequently, affecting evapotranspiration (Sentelhas, 2001).

Monthly average of daily ET_0 for all the PCS and open condition is presented in Fig. 4. Evapotranspiration (ET_0) under all structures tended to be lower than open field because of the greenhouse effect and the low radiation under these covers. Polyethylene sheet cover obtained the highest air temperatures and open field recorded the highest evapotranspiration during the whole season, which agreed with the results reported by Abdrabbo (2001) and Salman *et al.*(1992).The difference between internal and external evapotranspiration varies according to meteorological conditions. Estimated ET_0 of PCSis quite low when compared to that of irrigated crops outdoors for whole year. Fig. 4 shows that among PCS maximum ET_0 occurred inside the shadenet house (2.1 mm to 4.6 mm) for different months followed by walking tunnel (1.8 mm to 4.5 mm), polyhouse (1.9 mm to 4.1 mm) and MGH (1.8 mm to 4 mm).

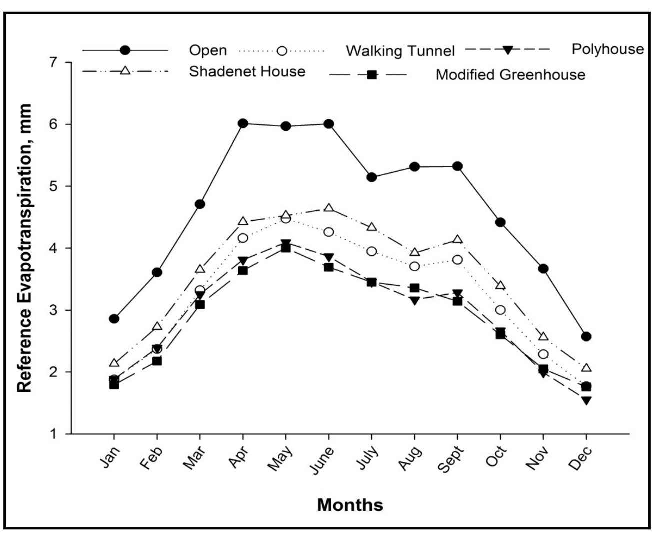

Fig. 4: Monthly average of daily reference crop evapotranspiration (mm) estimated for different PCS and open field condition

For poly house and MGH, values of estimated ET_0 are close in the range throughout the season but lesser values compare to walking tunnel and shadenet house. For winter months (December and January) estimated ET_0 values of walking tunnel, polyhouse and MGH are almost same. However, the trend is changed for summer and monsoon months in which estimated ET_0 values increased for walking tunnel compare to the polyhouse and MGH.

Many researchers have also observed that evapotran spiration inside a greenhouse is around 60 to 80% of that of outside (Montero *et al*., 1985 and Rosenberg *et al*., 1989). Farias *et al*. (1994) observed that the ET_0 inside PCS was always lower, ranging on 45 to 77% of that of verified outside. Braga and Klar (2000) observed that the values of ET_0 were 85 and 80% of the ET_0 verified outside for greenhouses oriented east/west and north/south, respectively. These results can be explained by the influence of the main factors of evaporative demand of the atmosphere, such as lower wind speed values, higher relative humidity and lower incidence of direct solar radiation inside greenhouses.

Crop water requirement:

The crop evapotranspiration was estimated by multiplying reference evapotranspiration with crop co-efficient based on crop growth stage. The amount of water required for capsicum under greenhouse varies from 0.37 L plant^{-1} Day^{-1} in January to 0.52 L plant^{-1} Day^{-1} in March. The amount of water required for capsicum under shadenet house varies from 0.42 L plant^{-1} Day^{-1}in January to 0.63 L plant^{-1} Day^{-1} in March. Total of 218.6 mm (49.20 L plant^{-1} season^{-1}), 252.9 mm (56.92 L plant^{-1} season^{-1}) and 339.7 (76.45 L plant^{-1} season^{-1}) of water is required to grow capsicum crop under poly house, shadenet house and in open field condition respectively. The amount of water required for cucumber under polyhouse varies from 0.31 L plant^{-1}

Day^{-1} in Aprilto 0.41 L $plant^{-1}$ Day^{-1} in June. Total of 364.52 mm and 540 mm of water is required to grow cucumber crop under polyhouse and open field condition, respectively. Crop water requirement of lettuce crop was estimated 0.25 - 0.33 l $plant^{-1}$ Day^{-1} under polyhouse and 0.66 - 0.89 l $plant^{-1}$ Day^{-1} for open field cultivation. Seasonal water requirement of Lettuce crop using drip irrigation was estimated 219 mm for polyhouse and 339 mm for open field condition. Total of 999 mm, 947 mm and 1120 mm of water is required to grow dutchrose crop under polyhouse, modified greenhouse and open field condition, respectively.

Crop yield :

Yields of different crops under PCS were found grater compare to open field condition. Research found anaverage 212 flowers/m^2/year, 221 flowers/m^2/year and 148 flowers/m^2/year produced under polyhouse, modified greenhouse and in open field conditions. Average yield of capsicum crop of 124.57 t ha^{-1} and71.72 t ha^{-1} were recorded under polyhouse and shadenet house, respectively. Average yield of cucumber of 7.07 kg $plant^{-1}$ and 4.03 kg $plant^{-1}$ were recorded under polyhouse and open field condition, respectively. Kirnak *et al.* (2016) also reported similar findings, which indicated that controlled environment by PCS significantly influenced growth and yield of lettuce.

Cost economics:

The high quality and off-season produce under PCS can fetch a better price in the market and can give higher income to the farmers. Economic analysis of dutch rose crop cultivation under greenhouse and open field conditions shows maximum B-C ratio of 2.0 for polyhouse, 2.4 for modified greenhouse and 1.4 for open field condition. Benefit cost ratio estimated as 3.2, 2.6 and 1.4 for capsicum crop cultivation under greenhouse, shadenet house and open field cultivation. The economic analysis of cucumber crop cultivation under walking tunnel shows higher B-C ratio (3.8) compare to open field condition B-C ratio (1.6).

Conclusion :

Protected cultivation structures offer a great solar energy saver and increased temperature inside structures. Due to increased temperature in protected cultivation structures, reference crop evapotranspiration also vary according to temperature and radiation. ET_0 estimated outside the PCS shows values higher than those for ET_0 estimated inside. Horticultural production in open field condition requires higher irrigation water requirement compare to the crops grown in PCS. Research experiments conducted indicated greater crop yield and higher profit by cultivating vegetable and flower crops under PCS compare to open field condition.

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