Environment and Ecology 42 (4) : 1533—1540, October—December 2024
Article DOI: https://doi.org/10.60151/envec/WFYC5406
ISSN 0970-0420

Temperature and Light Intensity under Passively Cooled Natural Ventilated Polyhouse and Shade Net Structure During Summer Season

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Received 28 June 2024, Accepted 20 August 2024, Published on 18 October 2024

ABSTRACT

The high temperature & light intensity inside the natural ventilated polyhouse during summer season is major challenge for cultivation and is a major hindrance in utilizing the polyhouse for round the year cultivation. This study was conducted to evaluate the reduction of temperature & light intensity inside passively cooled polyhouse using various shading configuration in comparison to shade net structure. There is always increase & decrease in minimum & maximum temperature under the polyhouse and shade net structure respectively. The % light transmission under shade net structure is better than polyhouse. Among the various shading configuration, when shade net is used at 0.3 m above the polyhouse roof surface performs best in reducing the temperature inside the polyhouse. However the shade net structure performs better than passively cooled polyhouse using various shading configuration during summer season.

Keywords Temperature, Light intensity, Polyhouse, Shade net structure, Summer season.

INTRODUCTION

The productivity & quality of any produce is influenced by the genetic characteristics of the cultivar, agronomical and microclimate management. We can best manage agronomical management under open field cultivation but there is no control on microclimate around the plant (Rai 2020).The open field microclimates varies season wise throughout the year i.e. winter season, summer season & rainy season and the available microclimates is not suitable for vegetable cultivation. The most obvious challenges during winter season, summer season & rainy season are respectively low temperature, high temperature & light intensity and rainfall apart from other challenges i.e. high wind speed, insect & pest, hailstorm. The protected structure can be used to provide suitable microclimate around the plant, which is fully & partially controlled to protect the crop from adverse open field microclimates.

The various protected structures used for protected cultivation are polyhouse and net structure

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(shade net structure and insect proof net structure) (Rai 2020). Each protected structures has its own advantages and disadvantages, the basic issues are fixed cost & operating cost to make the microclimate suitable for round the year cultivation, so that selected protected structure is economically viable and profitable.

A polyhouse is a framed structure covered with a transparent material and due to greenhouse effect, the temperature inside the polyhouse is always more than the open field temperature (Baudoin *et al.* 2013).The shade net reduces the light intensity to mitigate the adverse effects of high temperatures, which depends upon shading factor, which describes the ability of a net to absorb or reflect a certain part of sun radiation and it depends on the color, mesh size, and texture of the net (Serra *et al.* 2020).

In open field during summer season, the temperature & light intensity is already more than desirable for vegetable cultivation and due to greenhouse effect it further increases inside the polyhouse. To reduce the temperature of polyhouse during summer season, the passive and active cooling system can be utilized (Nikolaou *et al.* 2019). The challenges of using active cooling system are high fixed cost, operating cost, operational challenges and higher carbon footprint (Ntinas *et al*. 2020).

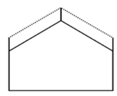
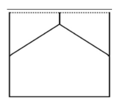
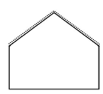
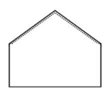
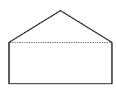
The commonly used passive cooled technologies for cooling polyhouse are natural ventilation and heat prevention using shading & radiation filters (García *et al.* 2011). The natural ventilation & shading is still used in many regions of the world with warm climates as they are simple and economically viable (Meca *et al.* 2013). The shade net is used to regulate the amount of solar energy entering the greenhouse and reduce the heating load in summer.

Though researchers have used shade net during summer season to reduce the light intensity & temperature but they have mounted shade net mainly externally and internally of the polyhouse. This study was planned to study the efficacy of passively cooled natural ventilated polyhouse during summer season using shade net at various external & internal position on temperature & light intensity in comparison to shade net structure.

MATERIALS AND METHODS

The experiment was conducted at research farm (longitude: 85.318°E, latitude: 23.448°N) of the AICRP on Plastic Engineering in Agriculture Structure and Environment Management (PEASEM), Department of Agricultural Engineering, Birsa Agricultural University, Kanke, Ranchi, Jharkhand. For this study the protected structures i.e. natural ventilated polyhouse (NVP) & shade net structure were constructed and different materials used were i.e. bamboo, GI wire, coal tar, waste plastic, nail, cladding materials (UV stabilized clear film (200 micron), UV stabilized insect net proof material (40 mesh) and shade net material (green, nominal shade rating: 50%)). The specification of protected structures were, length: 12 m, width: 4.5 m, side height: 1.5 m, central height: 2.25 m and door width: 1 m & height: 1.5 m.

Table 1. The shade net at various shading configuration.

Sl. No.	Shade net position	Various shading configuration (shade net shown as dotted line) over and under polyhouse
1	Shade net at 0.3 m over the polyhouse roof surface	
2	Shade net at 0.3 m over the center pole and horizontal	
3	Shade net fixed on cladding material	
4.	Shade net fixed just under the cladding material	
5.	Shade net inside the greenhouse	

The daily minimum & maximum temperature in open field, polyhouse and shade net structure were recorded using a minimum & maximum thermometer (ZEAL: UK, range: -40ºC to 50ºC, least count: 1ºC). The light intensity in open field, polyhouse and shade net structure were recorded at 10 AM and 2.30 PM daily using a lux meter (Lutron: Tiwan, range: 0-200 klux, least count: 0.01 lux, accuracy: ±3%). The shade net was used for passive cooling of the polyhouse and it was fixed at various shading configuration as shown in Table 1. The weekly microclimate (minimum & maximum temperature and light intensity) data fo ropen field, passively cooled polyhouse using shade net and shade net structure are used for performance study.

RESULTS AND DISCUSSION

The variation of temperature & light intensity under passively cooled natural ventilated polyhouse using the shade net at various shading configuration and shade net structure during summer season is discussed under this section.

Shading configuration I: Shade net at 0.3 m above the polyhouse roof surface

The Table 2 shows minimum & maximum temperature and light intensity & % light transmission under open field, polyhouse & shade net structure. The minimum & maximum temperature varied between 18.6 to 38.3ºC, 20.3 to 40.3ºC and 16 to 34.8ºC respectively under open field, polyhouse and shade net structure.

There is 1.7ºC increase in minimum temperature and 2ºC increase in maximum temperature recorded under polyhouse in comparison open field. It has been reported that the increase in minimum temperature under polyhouse is only between 1 to 3ºC due to higher heat loss during night period (Rai 2018). It is widely reported that the increase in maximum temperature under natural ventilated polyhouse is between 5 to 10ºC (Badji *et al*. 2022) but when the shade net is used for cooling of natural ventilated polyhouse, it reduces the maximum temperature by 3-5°C in comparison to natural ventilated polyhouse (Hatem *et al.* 2008). Ghosal *et al.* (2003) reported that under when naturally ventilated even-span greenhouse was shaded with well-knitted jute cloth under wet & dry conditions, compared to the unshaded greenhouse, the reduction in air temperature was 6ºC under wet shading and was 2ºC under dry shading.

But it is found that under shade net structure there is 2.6ºC decrease in minimum temperature and 3.5ºC decrease in maximum temperature in comparison open field. The decrease in minimum temperature may be due to non availability of solar radiation during night period (Möller *et al*. 2010). Waggoner *et al.* (1959) reported that in an empty tobacco screen house, the inside air was cooler by 1.5-2ºC at near midnight in comparison to open field. They concluded that the screen also emits radiation to the sky and thus cools the adjacent air layer, therefore, the air inside the screen house was cooler than open field, presumably due to the sinking of cool air from the screen above. Depending upon the shade net material used, it reduces the light intensity/solar energy and hence reduces the temperature under shade net structure (Castellano *et al.* 2008) and similar observation is reported by Milenkovic *et al.* (2012). Though the basic purpose of shade net is to reduce radiation & air velocity but its effect on temperature is much more complicated and it depended upon several simultaneous energy transfer processes, radiation exchange, convection & evapotranspiration (Tanny 2013).

The % light transmission varies between 19.6

Table 2. Shade net at 0.3 m above the polyhouse roof surface.

Sl. No.	Condition	Temperature (ºC) Minimum	Maximum	Light intensity (Klux) 10 AM	% Transmission	2 PM	% Transmission
1	Open field	18.6	38.3	67.9	-	85.8	-
2	Polyhouse	20.3	40.3	40.1	59.1	16.8	19.6
3	Shade net structure	16	34.8	21.2	31.2	32.2	37.5

Table 3. Shade net at 0.3 m above the center pole and horizontal.

Sl. No.	Condition	Temperature (ºC) Minimum	Maximum	Light intensity (Klux) 10 AM	% Transmission	2 PM	% Transmission
1	Open field	19.7	41.2	58.4	-	83.1	-
2	Polyhouse	20.5	44.2	22.1	37.8	14.9	17.9
3	Shade net structure	16.7	40.5	16.0	27.4	29.4	35.4

to 59.1 and 31.2 to 37.5 under polyhouse and shade net structure respectively. The % light transmission under polyhouse and shade net structure depends upon % light transmission property of both polyhouse cladding material & shade net material and only shade net material respectively. The average light transmissivity of a new polyhouse cladding material is about 86%, which can reduce up to 40% due to accumulation of dust & dirt on the exterior surface of the cladding material. The characteristics of the polyhouse cladding material also affect the level and quality of the transmitted radiation (Jaffrin and Morisot 1994). The reduction in % light transmission for shade net is due to shade net material (color (green) and nominal shade rating (50%)) and it is affected by shade factor, weaving type, color (Mditshwa *et al.* 2019). Möller *et al.* (2010) reported that for shading screenhouse covering a banana plantation, the screen transmission decreased linearly with time by about 0.1% day^{-1} during the rainless summer due to dust accumulation on the screen. Möller and Assouline (2007) concluded that % light transmission decreased with decrease in solar elevation angle.

Shading configuration II: Shade net at 0.3 m above the center pole and horizontal

It is clear from Table 3 that the increase in minimum & maximum temperature under polyhouse in comparison to open field is 0.8ºC and 3ºC respectively. But under shade net structure there is decrease in both for minimum & maximum temperature in comparison to open field and it is 3ºC and 0.7ºC respectively. The % light transmission varies between 17.9 to 37.8 and 27.4 to 35.4 under polyhouse and shade net structure respectively.

Overall similar trends have been found for temperature and % light transmission for polyhouse with shading configuration I and shade net structure. The shade net structure is more efficient in reducing the temperature during summer season in comparison to polyhouse and the availability of light intensity also under shade net structure is better than polyhouse.

Shading configuration III: Shade net fixed on cladding material

It is clear from Table 4 that the increase in minimum & maximum temperature under polyhouse in comparison to open field is 0.8ºC and 3.8ºC respectively. But under shade net structure there is decrease in both for minimum & maximum temperature in comparison to open field and it is 3.2ºC and 1.4ºC respectively. The % light transmission varies between 19.5 to 25.9 and 21.1 to 35.2 under polyhouse and shade net structure

Table 4. Shade net fixed on cladding material.

Sl. No.	Condition	Temperature (ºC) Minimum	Maximum	Light intensity (Klux) 10 AM	% Transmission	2 PM	% Transmission
1	Open field	16.4	36.4	58.2	-	87.8	-
2	Polyhouse	17.2	40.2	15.1	25.9	17.1	19.5
3	Shade net structure	13.2	35	12.3	21.1	30.9	35.2

Table 5. Shade net fixed just inside the cladding material.

Sl. No.	Condition	Temperature (⁰C) Minimum	Maximum	Light intensity (Klux) 10 AM	% Transmission	2 PM	% Transmission
1	Open field	21	40.5	57.4	-	83.9	-
2	Polyhouse	21.5	43.7	13.7	23.9	12.6	15.0
3	Shade net structure	17.5	39.2	14.6	25.4	26.6	31.7

respectively.

Overall similar observations have been found for temperature and % light transmission for polyhouse with shading configuration I & II and shade net structure. For this configuration also the shade net structure is more efficient than polyhouse in reducing the temperature during summer season and there is more reduction in light intensity under polyhouse in comparison to shade net structure.

Shading configuration IV: Shade net fixed just inside the cladding material

It is clear from Table 5 that the increase in minimum & maximum temperature under polyhouse in comparison to open field is 0.5⁰C and 3.2⁰C respectively. But under shade net structure there is decrease in both for minimum & maximum temperature in comparison to open field and it is 3.5⁰C and 1.3⁰C respectively. The % light transmission varies between 15 to 23.9 and 25.4 to 31.7 under polyhouse and shade net structure respectively.

Chen *et al.* (2011) reported that internal roof shading (50% transmissivity) has a significant effect on reducing the inside air temperature in a naturally ventilated greenhouse compared to that without shading especially during summer periods. The increase in temperature was only 2.7⁰C in a case of internal shading compared to 6⁰C in a case of without internal shading in comparison to open field.

Overall similar performance has been found for temperature and % light transmission for polyhouse with shading configuration I, II & III and shade net structure. In this case also, the shade net structure is more efficient than polyhouse in reducing the temperature and the availability of light intensity is lower under polyhouse in comparison to shade net structure which is not at all desirable.

Shading configuration V: Shade net inside the polyhouse

It is clear from Table 6 that the increase in minimum & maximum temperature under polyhouse in comparison to open field is 0.7⁰C and 4.5⁰C respectively. But under shade net structure there is decrease in both for minimum & maximum temperature in comparison to open field and it is 2.6⁰C and 0.8⁰C respectively. The % light transmission varies between 7.4 to 13.4 and 22.6 to 35.6 under polyhouse and shade net structure respectively.

The increase in maximum temperature is 4.5⁰C, which is highest among the other various shading configuration I, II, III & IV used to passively cool

Table 6. Shade net inside the greenhouse.

Sl. No.	Condition	Temperature (⁰C) Minimum	Maximum	Light intensity (Klux) 10 AM	% Transmission	2 PM	% Transmission
1	Open field	20.3	41.5	63.7	-	84.6	-
2	Polyhouse	21	46	4.7	7.4	11.3	13.4
3	Shade net structure	17.7	40.7	14.4	22.6	30.1	35.6

the polyhouse. Abdel-Ghany *et al.* (2015) concluded that for this shading configuration, when the shade net is fully deployed, it decreases the effectiveness of the natural roof ventilation and negatively affects the polyhouse microclimate. The shade net absorbs a portion of solar radiation, reemits it again in the polyhouse, and reflects back a portion also inside the polyhouse. Therefore, the effect of internal shading on reducing the polyhouse air temperature is expected to be small.

Overall similar observations have been found for temperature and % light transmission for polyhouse with shading configuration I, II, III & IV and shade net structure. The reduction in temperature under polyhouse for this shading configuration is lowest in comparison toother shading configuration I, II, III & IV. Here also shade net structure performs better in reducing the temperature in comparison to polyhouse and the availability of light intensity is lowest under polyhouse in comparison to other shading configuration I, II, III & IV, which is not at all desirable.

Overall performance

The natural ventilated polyhouse is passively cooled using various shading configuration I, II, III, IV & V and its performance is compared with shade net structure. The temperature recorded under polyhouse for shading configuration I, II, III, IV & V is higher than temperature recorded in open field and increase in maximum temperature varies between 2.0^{0}C to 4.5^{0}C. Among the various shading configuration I, II, III, IV & V, the shading configuration I is best with lowest increase in maximum temperature of 2.0^{0}C in comparison to open field. But requirement during summer season is to reduce the open field temperature and shade net structure reduces the maximum temperature between 0.7^{0}C to 3.5^{0}C. The open field temperature during summer season is already higher than required for cultivation and due to greenhouse effect the temperature under polyhouse further increases and shade net used for passively cooling the natural ventilated polyhouse is not very efficient. The reduction in light intensity under polyhouse under different shading configuration I, II, III, IV & V is much lower than those desirable for successful cultivation. The shade net structure is more efficient in reducing the temperature & light intensity in comparison to passively cooled natural ventilated polyhouse using different shading configuration I, II, III, IV & V.

Though shade net structure is more suitable than passively cooled natural ventilated polyhouse with shade net during summer season but major challenge of shade net structure is its utilization during rainy & winter season (Topno and Rai 2024). The temporary shade net structure is better choice than permanent shade net structure for cultivation of vegetables during summer season (Rai 2020).

The natural ventilated polyhouse can be used for round the year cultivation but there is need to find out suitable passive cooling system for summer season with lower fixed & operating cost. Rai (2018) has developed a passive cooled detachable roof greenhouse which reduces the light intensity and decreases the inside polyhouse temperature by 2 to 3°C. Rai (2022) has used IR reflective polyhouse film to passively reduce the polyhouse temperature during summer season and the mean temperature during summer season under IR reflective film polyhouse is 5°C lower than temperature under clear film polyhouse, which is same as open field temperature. Rai (2024) has further modified the detachable roof polyhouse with active cooling system using fogger to further improve the performance of polyhouse during summer season. The performance of detachable roof polyhouse with fogger was evaluated during summer season and it has been found that there is reduction in maximum temperature between 2.5-7.5°C with average drop of 6.5°C in comparison to open field.

CONCLUSION

This study was conducted to evaluate the performance of passively cooled polyhouse using various shading configuration with shade net structure for reducing the temperature & light intensity during summer season. The increase & decrease in minimum & maximum temperature inside the polyhouse and shade net structure varied between 0.5°C to 4.5°C and 0.7°C to 3.5°C respectively. Similarly % light transmission varied between 7.4 to 59.1 and 21.1 to 37.5 for polyhouse and shade net structure respectively. Among the various shading configuration, when shade net is used at 0.3 m above the polyhouse roof surface performs best in reducing the temperature inside the polyhouse. During the summer season, it is desirable to reduce the temperature but due to greenhouse effect, the polyhouse always increases the inside temperature even after passive cooling using shade net. The shade net structure performs comparatively better than passively cooled polyhouse for providing suitable temperature & light intensity. But there is need to develop more efficient cooling system for polyhouse which is sustainable & profitable such as the detachable roof polyhouse, detachable roof polyhouse with fogger, infrared reflective polyhouse which performs better during summer season in comparison to passively cooled natural ventilated polyhouse with shade net.

ACKNOWLEDGMENT

The authors express his sincere gratitude to the Indian Council of Agricultural Research, New Delhi for providing financial support through the AICRP on Plastic Engineering in Agriculture Structures & Environment Management (earlier PET), BAU, Ranchi to carry out the research work.

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