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Effect of greenhouse cover spectral properties on rose yield for Ethiopia highland

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ABSTRACT: In different agro-climates the greenhouse horticulture are making use of various types of plastic cover where its influence on production in relation to crop, indoor climate and outside climate not considered in selection. In this study, major spectral properties of mainly used greenhouse cover for Ethiopian highland and their effect on yield were investigated. Cover spectral properties such as cover near-infrared (NIR) transmission, photosynthetic active radiation (PAR) transmission and cover longwave emission coefficient were major parameters that are considered in this study to determine their effect on dry matter harvest. To examine the influence of the cover parameters on biomass production, a generic tool or a model constructed in Matlab software was used. The model comprises energy balance equations, mass balance equations and growth model. The measured greenhouse indoor temperature data was considered for validation of the model. Simulations of indoor temperature, canopy temperature and vapor concentration were conducted for the existing greenhouse configuration.

The result of the simulation showed that in Ethiopian greenhouse for highland, high and low temperature, night time high humidity and low CO_2 during day time are major problems which inhibit the growth and on the other hand create favorable condition for well know disease in the region that is botrytis. According to sensitivity analysis output of the model, 1% increase in PAR transmission resulted 0.009% increase dry matter harvest, whereas a percent increase in cover NIR transmission has caused 0.259% reduction in yield. Moreover, increment of cover long wave emission coefficient by 1 percent positively influences (0.044%) the rose production. The resulted depicted that as compared to low temperature problem during rainy season (2-3 months), high temperature problem during summer season (9-10 months) would become a foremost problem in Ethiopian highland greenhouse horticulture. Thus, plastic cover with lower NIR transmission and higher PAR transmission and long-wave emission coefficient is desirable for Ethiopian highland greenhouses.

However, the study revealed that night time low temperature particularly during rainy season should be studied to incorporate in respective growth model.

KEYWORDS: longwave emission, PAR transmission, NIR transmission, sensitivty analysis, spectral properties.

1 BACKGROUND

Floriculture in Ethiopia is a young industry and started in 1999 in the highland of the country near the capital, Addis Ababa and exporting mainly started in 2000 [11], [2].

Addis Ababa is located at latitude 8^0 N of Equator; longitude 38^0 E of Greenwich, place for some growers at the vicinity.

In Ethiopian highland due to low temperature and high RH% in the greenhouse, there has been a botrytis problem, which affects the growth performance of the rose. According to data obtained from highland greenhouse, Lafto Rose farm PLC, at night time during winter at least for two months the mean temperature gets below 10^oC and mean relative humidity greater than 80%, which might greatly affect the rose productivity in addition to favoring the disease even though net profit remains.

Danse et al.,[5] pointed out that downy mildew and botrytis are the major problems in Ethiopian greenhouse cultivation during the rainy season and mainly induced by low temperature.

In Ethiopian floriculture companies there are three major problems: undesirable greenhouse indoor climate, pest-disease and environment linked problem. Environmental problem can be either due to water use and/ or high chemical application which is the result of pest-disease infestation.

Production or yield loss in greenhouse rose cultivation can occur due to pest-disease infestation, undesirable high and low temperature and relative humidity.

Therefore, though the growers in this region still produce profitable, it is possible to bring up the production to a higher level by improving indoor climate conditions as well as reducing environmental load owing to the fact that high chemical application for pest-disease. Production loss in the region due to undesirable indoor climate is not clearly identified or quantified yet.

Minimizing extreme greenhouse temperature and relative humidity will improve the number of harvested stems per unit area and also minimize the incidence of pest-diseases. High temperature and low temperature problems in highland of Ethiopia and undesirable relative humidity can be solved by applying the knowledge of climate control techniques, which include the use of appropriate cladding material, best possible ventilation area, passive heating or cooling strategies and/or ventilation control strategy. To analyze and improve the indoor climate of the greenhouses and increase the yield per unit area, a tool or model which takes into account the influence of all the important design parameters on crop yield will be crucial.

Predicting the temperatures of air, plant, cover and soil, relative humidity, transpiration and evaporation based on either conducting experiments or simulation models essentially can help greenhouse designers to improve the greenhouse design to obtain an environment suitable for crop growth. As compared to conducting experiments, simulation methods provide a quick, less expensive and more flexible and repeatable way provided that the model is reliable. In the past there have been different simulation or mathematical models developed that rely on the energy balance analysis. Principally, these models were used to predict the greenhouse indoor climate as function of outdoor climate and parameters of the greenhouse elements [1].

Jensen [10] explained structural design, the environment control system and the growing or plant culture system are equally important in the design of greenhouse. However, attention is given to one or two of the key components but fails owing to the lack of importance given to any one of the components.

Local technical, legal and economic conditions are the key aspects influencing the choice of greenhouse type by growers. By and large, local tradition and thought of compatibility with existing greenhouses play an important role in the decision making [7].

Frausto and Pieters [8], Ganguly and Ghosh [9] pointed out that, greenhouse climate models with high degree of complexity and lots of parameters that should be determined by calibration have been built in the past ten years . On the contrary to these deterministic models, there are also black box models which do not experience from the need to determine appropriate values for lots of parameters.

Now a day, it is clearly seen that there is no straightforward solution for designing a greenhouse which instigate continuous improvements originating from both experience and scientific research. This explains that most important types of greenhouses have vital functional and structural advantages and disadvantages [7].

In this regard, greenhouses that have been constructed in different locations of the world are very different in construction and cover materials, climate regulating mechanisms and crop growing media (soil or soiless).

The main factors for the variation are crop response, local climate, availability of water, soil and water quality, labor, availability of materials, expenditure (cost) and legislation.

A model or generic tool which takes into consideration the influence of cover properties, passive heating/cooling and ventilation area on greenhouse climate and yield, regarding passive optimal greenhouse design introduced by Wageningen University and Plant Research International (PRI) was employed in this paper. The tool was set up as an integral approach and constructed in Matlab to execute sensitivity analysis of selected design parameters and simulation of indoor climate and yield.

OBJECTIVE

The purpose of this research to determine the effect of cover properties on yield that means on indoor climate. The output of this research will enable to growers and greenhouse horticulture designer to look for best possible or optimum type of cover material.

2 MATERIALS AND METHOD

For major varieties of rose grown in Ethiopian highland their response to temperature, RH%, light and CO_2 were reviewed so as to make set point. For specific variety grown in Ethiopian PAR requirements is 700-900µmol/m^2/s [16], temperature requirements is 17-25^{0}C [17] and relative humidity requirements should be 60-80% [14].

The model comprises of state variables that vary with time (greenhouse air temperature, canopy temperature, soil temperature, vapor concentration of greenhouse air, greenhouse CO_2 concentration and total biomass), control inputs (shade screen, white wash and ventilation opening control) and external inputs (solar radiation, wind speed, outdoor temperature, outdoor air vapor concentration and outdoor air CO_2 concentration). The model output is in hourly values and thus the external inputs were in hourly basis. Hence, hourly sky global radiation value was calculated and other external inputs except CO_2 were collected from Ethiopian meteorological agency. Outdoor CO_2 concentration was assumed to be constant that is 340ppm.

The various equations which were used in the model and computed by ode (15) of Matlab:

2.1 ENERGY BALANCE IN GENERIC TOOL

According to Bot, (1983) as quoted by El Ghoumari et al., [6] the dynamic behavior of state variables (temperature, humidity and CO_2) within the greenhouse is governed by the energy and mass balances. The energy balance which influences greenhouse temperature is affected by the energy contribution of the heating system, the energy losses caused by the energy exchange between the cover and the outside environment as well as through the natural ventilation provided by the windows, and finally the energy contribution of the solar radiation.

The heat fluxes among different components of the greenhouse (cover, soil, crop and air) were introduced in the generic tool indicated in the equations below. Radiative and convective heat exchanges among the components were described in the energy balances of the states.

ENERGY BALANCE FOR THE GREENHOUSE AIR TEMPERATURE

To compute the greenhouse temperature at different time instant, the differential equation which contains the different convective heat fluxes has been stated as shown below (eq.1).

$$Cap_{Air}\frac{dT_{Air}}{dt} = H_{canair} - H_{AirOut} - H_{Airflr} - H_{air\,cov}.......[Wm^{-2}] \qquad (1)$$

ENERGY BALANCE FOR THE COVER TEMPERATURE

To compute the cover temperature at different time instant, near infrared and PAR components of the solar radiation, longwave radiation fluxes and convective heat fluxes among different bodies were listed out in the differential equation stated below (eq.2):

$$Cap_{\mathrm{cov}}\frac{dT_{\mathrm{cov}}}{dt} = R_{sun\,\mathrm{cov}} + H_{air\,\mathrm{cov}} + L_{air\,\mathrm{cov}} + R\_TIR_{can\,\mathrm{cov}} + R\_TIR_{flr\,\mathrm{cov}} - H_{\mathrm{cov}\,out} - R\_TIR_{\mathrm{cov}\,Ssy}............[Wm^{-2}] \qquad (2)$$

ENERGY BALANCE FOR THE CANOPY TEMPERATURE

Similar to cover temperature computation, the differential equation of canopy temperature comprises near infrared and PAR portion of solar radiation, longwave heat fluxes and convective heat fluxes among various greenhouse components indicated in the equation below (eq.3).

$$Cap_{can}\frac{dT_{can}}{dt} = R\_PAR_{suncan} + R\_NIR_{suncan} - H_{canair} - L_{canair}$$
$$- R\_TIR_{can\text{cov}} - R\_TIR_{canflr} - R\_TIR_{cansky} \text{............}[Wm^{-2}] \quad (3)$$

ENERGY BALANCE FOR GREENHOUSE FLOOR TEMPERATURE

To calculate the greenhouse soil temperature at different time instant, in the same manner, near infrared and PAR portion of solar radiation, longwave heat fluxes and convective heat fluxes among greenhouse components were taken into account, described in the equation below (eq.4):

$$Cap_{flr}\frac{dT_{flr}}{dt} = R\_PAR_{sunflr} + R\_NIR_{sunflr} + H_{airflr} +$$
$$R\_TIR_{canflr} - R\_TIR_{flr\text{cov}} - H_{flrso1} - R\_TIR_{flrsky} \text{..........}[Wm^{-2}] \quad (4)$$

2.2 VENTILATION FLUX

Natural ventilation is caused by pressure differences between the indoor and outdoor air which are induced by two main forces: wind action and buoyancy or stack effect [3], [4].

VENTILATION FLUX FOR ROOF OR SIDE OPENING ONLY

This module of ventilation flux computation is used when the greenhouse is equipped with either roof or side opening only [15].

$$f_{vent} = \frac{A}{2}C_d\sqrt{2g(h/4)\frac{(T_{air} - T_{out})}{T_m} + C_w * V_{speed}{}^2} \text{...........}[m^3m^{-2}s^{-1}] \quad (5)$$

2.3 VAPOR BALANCE AND TRANSPIRATION

Vapor balance in the greenhouse should take into account crop transpiration, vapor loss due to ventilation and condensation on the cover. The, equation stated below (eq.6) was used to compute the vapor pressure in the greenhouse at different instant of time.

$$con\_VP_{air}\frac{dVP_{air}}{dt} = MV_{canair} - MV_{air\text{cov}} - MV_{airout} \text{.............}[kg.m.^{-3}s^{-1}] \quad (6)$$

Transpiration from the canopy is calculated based on the vapour pressure difference between the canopy and greenhouse air as stated below (eq.7):

$$MV_{canair} = VEC_{canair}(VP_{can} - VP_{air}) \text{............}[kg.s^{-1}.m^{-2}] \quad (7)$$

2.4 CARBON DIOXIDE BALANCE

Concerning carbon dioxide balance within the greenhouse, plants respiration and air exchange due to window ventilation affect carbon dioxide equilibrium [6].

Consequently, the following relationship was used to calculate the greenhouse carbon dioxide concentration. In the generic tool the carbon dioxide balance depends on the crop assimilation rate, respiration rate and flux through ventilation opening.

$$Gh\_h * \frac{dCO_{2air}}{dt} = MC_{crpair\_m} + MC_{crpair\_g} - MC_{aircrp} - MC_{airout} ....[kgm^{-2}s^{-2}] \quad (8)$$

2.5 GROSS PHOTOSYNTHESIS RATE FOR ROSE OR GROWTH MODEL

Obtaining a growth model which can fit the generic tool was investigated.

GENERIC TOOL GROWTH RATE CALCULATION APPROACH

The approach in generic tool to compute photosynthesis was performed by introducing inhibition factors for light and carbon dioxide. Here, the inhibition factors are introduced based on parameters p1 and p2 respectively as illustrated below. For each factor, these parameters are crop specific which would enable to fit the response of photosynthesis calculated by this approach with respect to response of rose to these factors obtained from literature, particularly the result of [12]. That means the trend of the inhibition factors should at least be similar to the trend of photosynthesis versus these factors.

$$MC_{aircrp} = h\_R_{can} * h\_CO_{2air} * MC_{aircrp\_pot} ....[g(CO_2)m^{-2}hr^{-1}] \quad (9)$$

$$h\_R_{can} = \frac{R_{can}}{p1 + R_{can}} ....[-] \quad (10)$$

$$h\_CO_{2air} = \frac{CO_{2air}}{p2 + CO_{2air}} ....[-] \quad (11)$$

$$MC_{aircrp\_h} = h\_Tcan * h\_Tcan24 * MC_{aircrp} ....[g(CO_2)m^{-2}hr^{-1}] \quad (12)$$

$$\frac{dYield}{dt} = HI * \beta\_CO_2\_CH_2O * \beta\_CH_2O\_DM * (MCaircrp - MCcrpair) ....[kg(DM)m^{-2}s^{-1}] \quad (13)$$

For temperature, a trapezoidal temperature filter was used for mean and instantaneous temperature of the canopy. The generic tool has these temperature inhibition factors based on the crop response to temperature, thus rose response to mean temperature and instantaneous temperature were considered as indicated in the figure 1**Erreur ! Source du renvoi introuvable.**. The inhibition factor ranges between one and zero, and when the temperature is in the optimal range, then the inhibition factor becomes one or there is no punishment. Otherwise there is a punishment when the temperature is out of the optimal range in both cases.

By taking into consideration MCaircrp_pot as canopy photosynthesis, it is possible to use this approach for this research work to compute net photosynthesis. And finally yield was calculated as harvested number of stems.

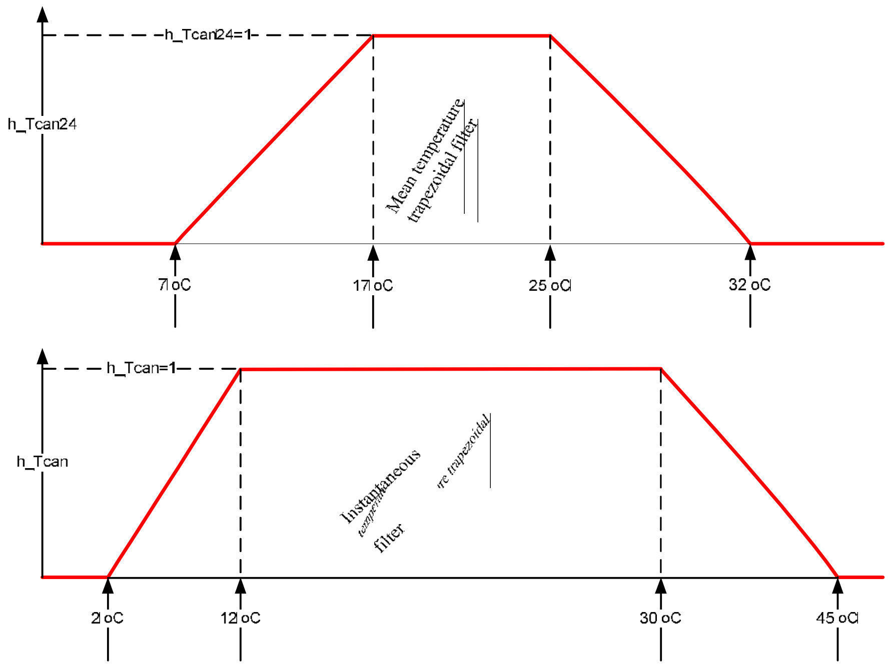

Figure 1.Temperature growth inhibition factor computation method

2.6 SENSITIVITY ANALYSIS FOR GREENHOUSE COVER PROPERTIES

In the sensitivity analysis, the extent of influence of selected parameters (cover PAR transmissivity, cover NIR transmissivity and cover longwave emission coefficient) on rose yield was calculated. This helps to analyze which parameter(s) influence the greenhouse indoor climate and dry matter production and extent of influence. Specifically, small change in design parameters and the resulting change in crop yield were computed.

In this analysis, the values of the existing Ethiopian greenhouse cover PAR and NIR transmissivity were considered as nominal value, then the percent change in dry matter production when these design parameters increased by 1% was calculated. The greenhouse cover which has been used by Ethiopian rose growers is assumed to be LDPE (a low-density polyethylene film) film, and it has 0.83 PAR transmissivity and 0.87 NIR transmissivity (nominal value) [13]. Also the ventilation area per span is 60 meter square per 960 m^2 floor area was considered. Moreover, cover nomial value for longwave emission coefficient is 0.67.

According to van Henten (1994) as cited by Vanthoor et al., [18], the relative sensitivity of yield for the design parameters is calculated as described below.

$$S_r(t) = \frac{Yield_{Pnom+\Delta p}(t) - Yield_{Pnom}(t)}{Yield_{Pnom}(t)} * \frac{P_{nom}}{\Delta P} \qquad (14)$$

$$\Delta P = h * P_{nom} \qquad (15)$$

Where, h is perturbation factor (0.01), $Yield_{Pnom}$ is the yield at nominal value of the design parameters, $Yield_{Pnom+\Delta P}$ is the increase in yield when the design parameter increased by 1 percent (h) and P_{nom} is the nominal value of the design parameters.

3 RESULT AND DISCUSSION

The validation of the model showed that there is little difference between simulated and measured greenhouse air temperature (Figure 2).

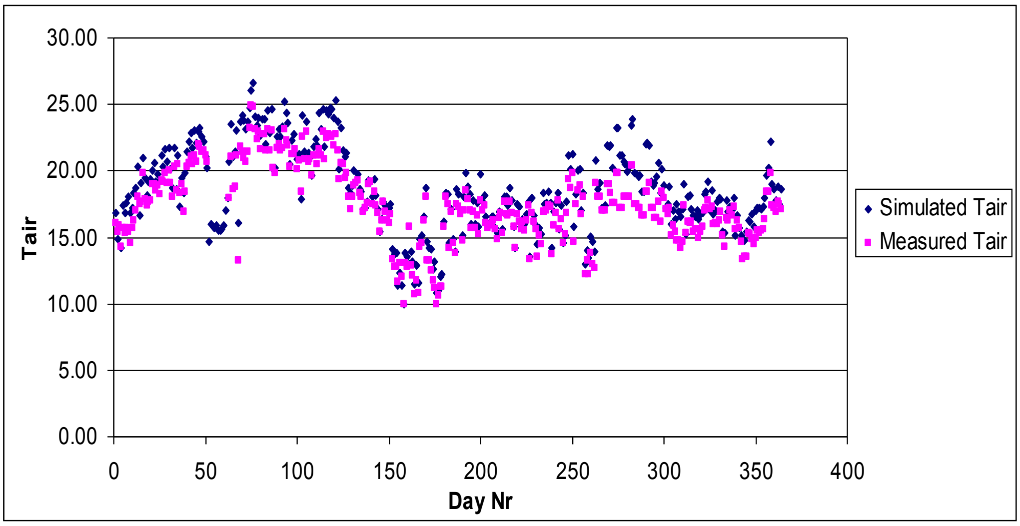

Figure 2. Comparison of simulated and measured mean daily greenhouse temperature

According to the sensitivity analysis executed, the influence of the parameters on dry matter production during summer and winter is quite different. As indicated in the table 2, the increase in PAR transmission by one percent during winter (rainy season) results in 0.647 percent increment in dry matter production, whereas a percent increase in PAR transmission in summer (dry season) results in 0.398 percent decrease in dry matter (table 1), where its impact is lower in reference to winter period. As figure shows, PAR transmission has high influence on canopy temperature, thus during winter period since the surrounding temperature is very low, higher PAR transmission would enable higher canopy temperature, consequently favors better photosynthesis. On the other hand, during summer period since the surrounding temperature is relatively high, higher PAR transmission would again result higher canopy temperature (figure 3), hence inhibits photosynthesis.

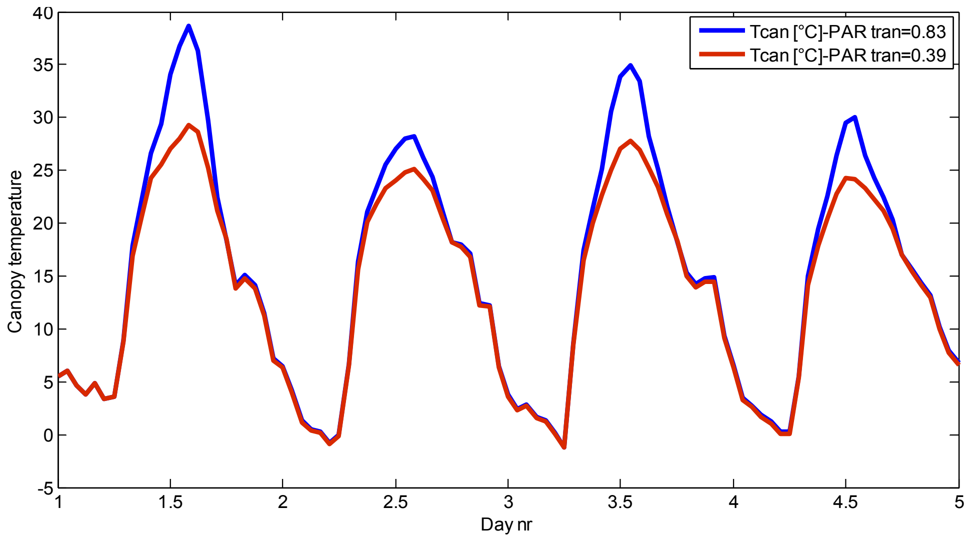

Figure 3. The effect of cover PAR transmissivity on canopy temperature

Moreover, the simulation result showed that (Figure 4) there is significant difference in the number of rose stems harvested per unit area for different PAR values.

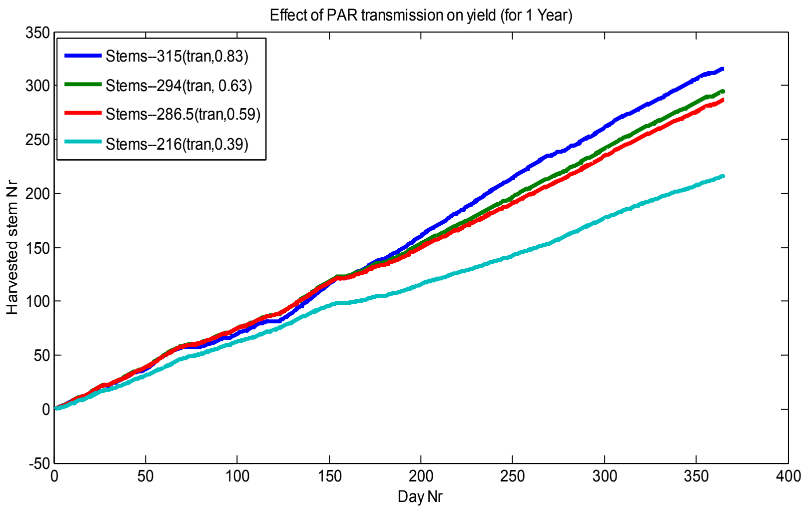

Figure 4. The effect PAR in the greenhouse on yield for one year

Concerning cover NIR transmissivity (table 1), during summer period it has high negative influence on dry matter harvest, that is, a percent increase in NIR transmissivity results in 0.409 percent decrement in dry matter, similarly, during winter the increase in NIR transmissivity lower the yield, but with small amount (0.009). From figure 5, the increase in NIR transmission resulted an increase of greenhouse air temperature, however, during summer period in particular, such increment would result a temperature range beyond the crop requirement in which it negatively influence the photosynthesis. Despite the increase in NIR resulted a decrease in yield for winter season, figure 5 clearly illustrated that low temperature is still a problem particularly during night time. Such night time undesirable climate punishment in production not yet included in any growth model.

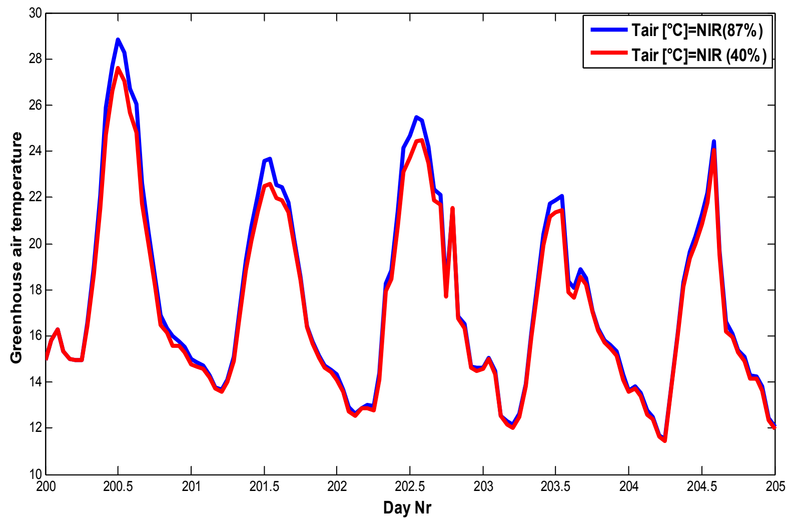

Figure 5. The effect of NIR transmissivity on greenhouse air temperature

Cover longwave emission coefficient has less influence on dry matter harvest when compare to the previous cover spectral properties. The sensitivity analysis illustrated that a percent increase in longwave emission coefficient during winter and summer season (table 1 and 2 respectively) has little positive influence on dry matter harvest. The positive influence of cover longwave emission coefficient during summer period (0.068% yield increment) due to the fact that high canopy temperature which adversely affect photosynthesis can be reduced by higher value of emission coefficient, that is, reducing the heat load would be possible. Similarly, during winter period since the canopy and indoor temperature are relatively lower, increased emission coefficient can further lower these temperatures, consequently production is negatively affected. Thus, this can be linked with its influence on the range of temperature that inhibits or favors production.

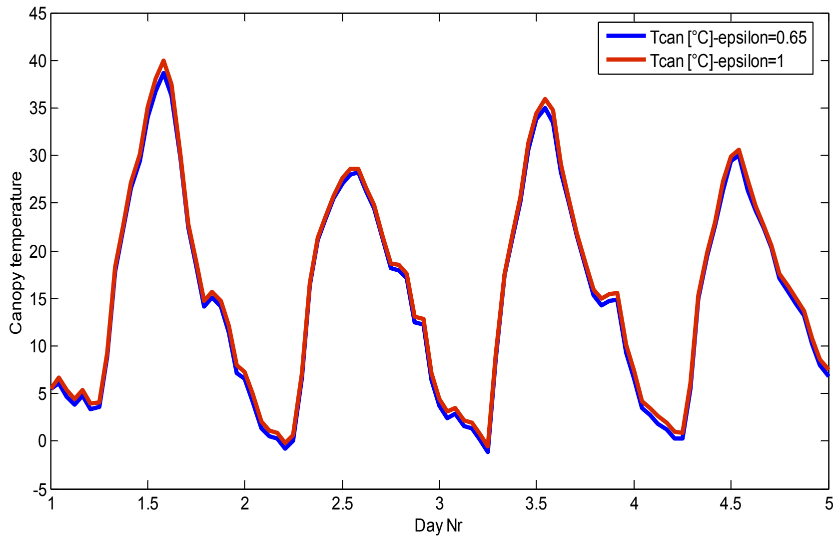

Figure 6. The effect of cover longwave emission coefficient on canopy temperature

In a yearly base assessment of integrated mean relative sensitivity (table 3), PAR transmission by 1% has resulted 0.009% increment on rose yield. The dry matter increment is notably low owing to the fact that PAR transmission has high influence on canopy temperature (table 3 and figure 1) which would consequently affect dry matter harvest.

However, percent increment in NIR transmission has significant influence in dry matter harvest (reduced by 0.25%). This is because of longer summer period in Ethiopia resulted higher indoor and canopy temperature and hence increment of NIR transmission would further increase these temperatures beyond crop requirement. Concerning cover longwave emission coefficient, its increment resulted in 0.044% higher production. As discussed by since heat load is high during longer period (summer), reduction of this heat load can be achieved by increasing the emission coefficient, thus, production can be favored.

Table.1 Integrated relative mean sensitivity analysis for summer season

	Integrated mean relative sensitivity/Summer period		
States	tau-PARcov	tau-NIRcov	epsilon-covup
Tcov	0.081	0.036	-0.125
Tair	0.104	0.047	-0.024
Tcan	0.19	0.079	-0.029
Tflr	0.15	0.117	-0.024
VPair	-0.024	-0.008	0.001
CO_2air	-0.002	0.003	-0.001
DM_{hararv}	-0.398	-0.409	0.068

Table 2 Integrated relative mean sensitivity analysis for winter season

Integrated relative mean sensitivity analysis/Winter period			
States	tau-PARcov	tau-NIRcov	epsilon-covup
Tcov	0.045	0.021	-0.119
Tair	0.062	0.029	-0.022
Tcan	0.109	0.047	-0.024
Tflr	0.09	0.086	-0.021
VPair	0.021	0.009	-0.006
CO2air	-0.007	0.002	-0.001
DM_{harv}	0.641	-0.009	-0.013

Table 3 Integrated relative mean sensitivity analysis for one year

	Integrated relative mean sensitivity analysis/One year		
States	`tau-PARcov	tau-NIRcov	epsilon-covup
Tcov	0.071	0.032	-0.13
Tair	0.093	0.042	-0.026
Tcan	0.166	0.07	-0.029
Tflr	0.133	0.11	-0.024
VPair	-0.002	0	-0.002
CO_{2air}	-0.005	0.002	-0.001
DM_{harv}	0.009	-0.259	0.044

4 CONCLUSION

To assess the influence of cover spectral properties growth model which encompasses effect of night time adverse climatic condition is very crucial

The study revealed that the existing cover NIR transmission has negative influence on production particularly during summer season. Thus, for this cover use of white wash would be advisable to reduce high indoor temperature.

For Ethiopian highland greenhouse horticulture cover with higher PAR transmission, relatively lower NIR transmission and higher long-wave emission coefficient will enhance rose production.

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SYMBOLS

Abbreviation/ symbol	*Description*	*Value*	*Unit*
β_CO_2_CH2O	Conversion factor from CO_2 to CH_2O	30/44	-
β_CH_2O_DM	Conversion factor from CH_2O to Dry matter	0.8	-
MCaircrp_h	Photosynthesis rate	-	$kg(CO_2)\ m^{-2}\ s^{-1}$
MCcrpair_m	Maintenance respiration rate		$kg(CO_2)\ m^{-2}\ s^{-1}$
tau_NIR	Cover near infrared transmissivity	0.87	-
tau_PAR	Cover PAR transmissivity	0.83	-
epsilon-covup	Cover long-wave emission coefficient	0.67	
A	Roof ventilation opening area	60	m^2
Cap_{Air}	Heat capacity of the air	10^3	$J\ m^{-2}\ K^{-1}$
Cap_{can}	Heat capacity of the canopy	$1.2*10^3$	$J\ m^{-2}K^{-1}$
Cap_{cov}	Heat capacity of the cover	$2.5*10^3$	$J\ m^{-2}\ K^{-1}$
Cd	Discharge coefficient	0.705	-
con_VP_{air}	Vapor pressure constant	-	$kg.m^{-3}.J^{-1}$
Cw	Global wind coefficient		-
DM_{harv}	Percent dry matter harvest	-	%
fvent	Ventilation flux	-	$m^3m^{-2}s^{-1}$
g	Acceleration due to gravity	9.8	$m\ s^{-2}$
h_CO_2air	Inhibition factor for CO2	-	-
h_Rcan	Inhibition factor for radiation	-	-
h_Tcan	Inhibition factor for temperature	-	-
h	vertical height of ventilation opening	6.2	m
Haircov	Sensible heat greenhouse air to cover	-	$W\ m^{-2}$

Hairflr	Sensible heat greenhouse air to the floor	-	$W\ m^{-2}$
Hairout	Sensible heat greenhouse air to the surrounding due to ventilation	-	$W\ m^{-2}$
Hcanair	Sensible heat canopy to air	-	$W\ m^{-2}$
Hcovout	Sensible heat cover to the surrounding	-	$W\ m^{-2}$
HEC	Convective heat exchange	-	$Wm^{-2}K^{-1}$
HECaircov	Convective heat exchange air to cover	-	$Wm^{-2}K^{-1}$
HECairflr	Convective heat exchange air to floor	-	$Wm^{-2}K^{-1}$
HECcanair	Convective heat exchange canopy to air	-	$Wm^{-2}K^{-1}$
Hflrsol	Sensible heat floor to soil	-	$W\ m^{-2}$
HI	Harvest Index	65	%
Laircov	Latent heat greenhouse air to cover	-	$W\ m^{-2}$
Mcaircrp	Crop CO_2 assimilation rate	-	kg (CO_2) $m^{-2}s$-^{1}
MCcrpair	Maintenance respiration		kg (CO_2) $m^{-2}\ s^{-1}$
Mcaircrp_pot	Potential crop CO_2 assimilation rate	-	kg $m^{-2}s^{-1}$
MVcanair	Vapor flux from canopy to air	-	$kg.s^{-1}.m^{-2}$
MVaircov	Vapor flux air to cover	-	$g\ m^{-2}\ s^{-1}$
PAR	Photosynthetic active radiation	-	µmole $m^{-2}s^{-1}$
NIR	Near Infrared	-	µmole $m^{-2}s^{-1}$
P1	Crop parameter for radiation inhibition	-	-
P2	Crop parameter for CO_2 inhibition	-	-
R_TIRcancov	Longwave radiation canopy to cover	-	$W\ m^{-2}$
R_TIRcanflr	Longwave radiation canopy to the soli	-	$W\ m^{-2}$
R_TIRcansky	Longwave radiation canopy to sky	-	$W\ m^{-2}$
R_TIRcovsky	Longwave radiation cover to sky	-	$W\ m^{-2}$
R_TIRflrcov	Longwave radiation the soil to the cover	-	$W\ m^{-2}$
R_TIRflrsky	Longwave radiation floor to sky	-	$W\ m^{-2}$
Tair	Greenhouse air temperature	-	^{o}C
Tcan	Canopy temperature	-	^{o}C
Tcov	Greenhouse cover temperature	-	^{o}C
Tflr	Floor temperature	-	^{o}C
Tm	Mean temperature	293	^{o}K
Tout	Surrounding temperature	-	^{o}C
Vspeed	Wind speed	-	$m\ s^{-1}$
VP_{can}	Vapor pressure on canpy	-	Pa
VP_{air}	Vapor pressure of greenhouse air	-	Pa
VEC_{canair}	Vapor exchange coefficient	-	$kg.s^{-1}.Pa^{-1}.m^{-2}$

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