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Mathematical model for nursery raising inside greenhouse

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Farmers require initially high input to raise nursery seedling/cuttings. Farmers' further activity related to cultivation depends on healthy and available seedlings. Once a farmer has prepared the land and cannot get good seedling, he becomes weak for some season. Studying of environment is a must for planning nursery raising according to thermal profile which can be obtained in greenhouse. Keeping this in mind, mathematical model was developed and evaluated for predicting thermal environment inside the 80 km^2 arch shaped greenhouse. The maximum increase in greenhouse air temperature was 13.92°C for solar radiation of 500 W/m^2 with 0°C ambient temperature. Experimental and calculated values of greenhouse temperature were almost the same with variation of 2 to 3°C. The theoretical values obtained from model were in reasonably good agreement with the experimental results. Therefore, the mathematical model could be used to predict temperature conditions inside the greenhouse for a variety of climatic parameters. Selection of plants' nursery inside the greenhouse was determined according to predicted thermal environment. As par the thermal profile found inside the greenhouse, plumery plants' nursery was selected and its sprouting, survival percentage and economic were calculated for the farmers' awareness.

Key words: Arch shaped greenhouse, mathematical model, nursery, economics.

INTRODUCTION

Farmers are looking towards the technology, which is economical and less laborious in present situation. Solution to such scenario of plants' nursery growing inside the greenhouse is best technology for year round production in water scarcity areas. For successful plantation programme, cuttings/seed must be raised first in nursery. Production of healthy seedlings is important where the planting stock is raised seed or cuttings and is maintained for some months (Thakur and Thakur, 1993). Cultivation of nursery also improves the overall growth of plant substantially in terms of height compared to outside condition. A study is therefore undertaken to find out the thermal environment inside the greenhouse by validation of thermal model for selection of suitable nursery in order to increase the germination and survival percentage of plants for higher benefits to farmers. It is also felt that developed model should be more versatile so that it can be used under any climatic conditions, all months and at any location. Accordingly, modified arch shaped greenhouse was selected for cultivation of nursery to perform better where cooling is required (Amita and Tiwari, 2002). An arch shaped greenhouse was designed covering a soil area of 13.4 m × 6.0 m, that is, 80 m^2 as shown in Figure 1. Orientation is in East-west direction.

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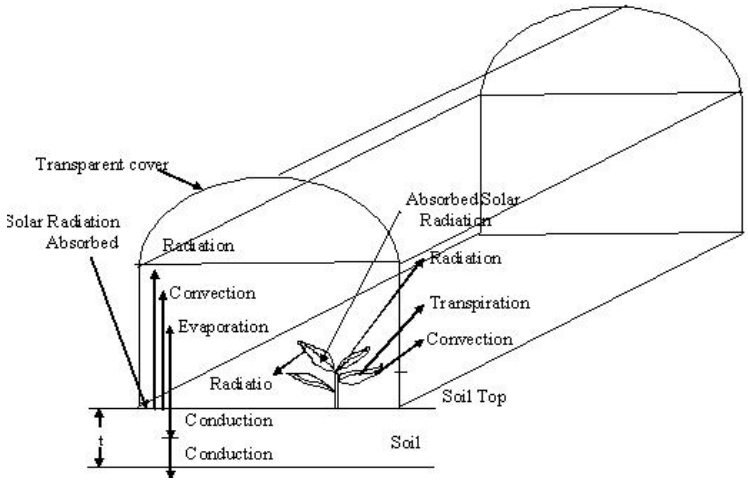

Figure 1. Energy transfer mechanism in greenhouse.

The greenhouse was covered by ultra violet stabilized low-density ethylene sheet of 200-micron thickness.

METHODLOGY

Here, various energy balance equation was validated for the prediction of thermal environment inside the arch shaped greenhouse. Effect of solar radiation and ambient temperature on greenhouse air temperature were also predicted through model. As par the predicted values for particular month, types of plants were selected for growing nursery inside the greenhouse. Predicted values were compared with observed values for finding the actual performance of sprouting percentage and survival percentage of plants. On the basis of growth parameter economics of this technology was calculated.

Energy balance analysis

By considering the number of complexities of the heat and mass transfer mechanisms occurring in greenhouse (Garg, 1987; Kaushick, 1988) (Figure 1), modeling the greenhouse as a single component is too cumbersome. Therefore, it is more rational approach to divide a greenhouse into separate components and model them independently. Mathematical models have been evaluated to predict the hourly variation in greenhouse environment, that is, temperature of cover, enclosed air, plants and soil surface and relative humidity of enclosed air for operating condition separately (Cooper and Fuller, 1983). The energy balance equations for finite difference technique and result for solving different components of the system were obtained by using computer programme prepared in Microsoft Office Excel. The energy transfer mechanism inside the greenhouse for greenhouse, plant and soil is shown in Figures 1 to 3.

The expression for temperature of cover, enclosed air, plants and soil surface and relative humidity of enclosed air can be written as

$$T_{co} = \frac{1}{D_4}[T_{st}A_4 + T_{gh}B_4 + T_pC_4 + E_4 + A_{co}(h_{coa}/1005)h_{sg}(W_{gh}-W \quad (1)$$

Where, $A_4 = A_{st}\ h_{rsco}$; $B_4 = A_{co}h_{coa}$; $C_4 = A_p\ h_{rpco}$ $D_4 = A_{co}h_{coa} + A_c\ h_{rcco} + A_p\ h_{rpco} + A_{co}h_{coo} + A_{co}\ h_{rcosky}$, , and $E_4 = I_{co}\ A_{co}\ \alpha_{co} + T_a\ A_{co}h_{coo} + T_{sky}\ A_{co}\ h_{rcosky}$.

$$T_{gh} = \frac{1}{B_3}[T_{st}A_3 + T_cC_3 + T_{co}\ D_3 + E_3] \quad (2)$$

Where, $A_3 = h_{sa}\ A_s$, $B_3 = h_{coa}\ A_{co} + h_{pa}\ A_p\ L_i + h_{sa}\ A_s + LVC_{pc}\ \rho_a + m_v\ C_{pa} + m_h\ C_{pa}$; $C_3 = h_{pa}\ A_p\ L_i$, $D_3 = h_{coa}\ A_{co}$, $E_3 = T_a(LVC_{pc}\ \rho_a + m_v\ C_{pa}) + T_h\ (m_h\ C_{pa})$

$$T_p = \frac{1}{C_2}[T_{st}\ A_2 + T_{gh}\ B_2 + E_2 - k_tL_iA_p(W_p - W_{gh})h_{sg}] \quad (3)$$

Where, $A_2 = h_{rps}\ A_p$, $B_2 = h_{pa}A_pL_i$; $C_2 = h_{pa}A_pL_i + h_{rps}A_p + h_{rpsky}A_p$, $E_2 = I_p\alpha_pA_p + h_{rpsky}A_pT_{sky}$.

$$T_{st} = \frac{1}{A_1}[\ T_{gh}\ B_1 + T_p\ C_1 + E_1 - h_{ds}\ h_{sg}\ (W_{st} - W_{gh})\ A_s] \quad (4)$$

Where, $A_1 = h_{sa}\ A_s + h_{rsp}\ A_s + \frac{kA_s}{t}$, $B_1 = h_{sa}\ A_s$, $C_1 = h_{rsc}\ A_s$, and $E_1 = \alpha_s\ Is\ A_s - \frac{kA_s}{t}\ T_{sb}$.

Humidity ratio

For determining W_{co}, W_p, W_{st} and W_{gh} saturation conditions can be assumed at the cover, leaf and soil surfaces. From psychrometric relations, various humidity terms can be written as follows.

$$W_{co} = 0.622 \times \frac{P_{sco}}{P - P_{sco}} \quad (5)$$

$$W_p = 0.622 \times \frac{P_{sp}}{P - P_{sp}} \quad (6)$$

$$W_{st} = 0.622 \times \frac{P_{sst}}{P - P_{sst}} \quad (7)$$

The mass balance equation for the greenhouse air could be written

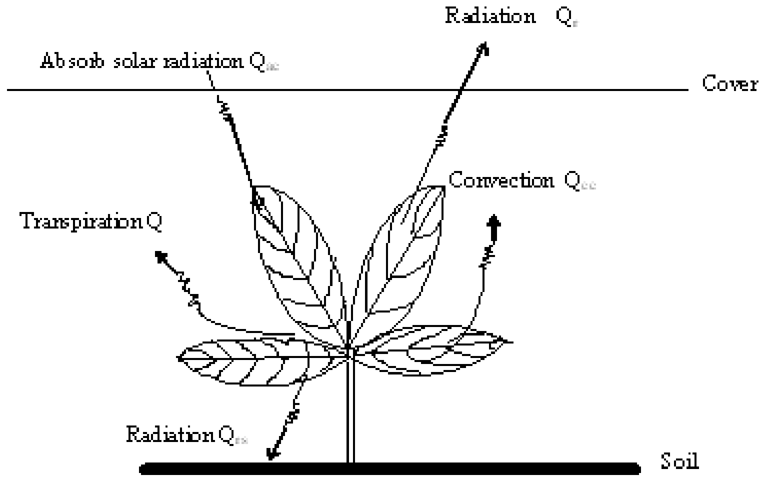

Figure 2. Energy transfer mechanism for plant.

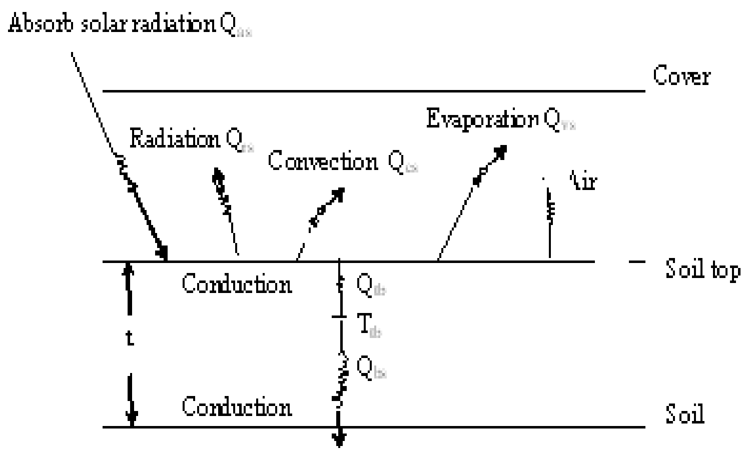

Figure 3. Energy transfer mechanism for soil.

as:

$$W_{gh} = 0.622 \times \phi \times \frac{P_{sgh}}{P - P_{sgh}} \quad (8)$$

Where ϕ is the relative humidity inside the greenhouse. The comparisons of different expressions developed by various researchers for calculating saturation vapour pressure corresponding to different temperatures were made with the steam table (Tiwari and Goyal, 1998). According to this expression, vapour pressure at saturation at cover, plant, soil and greenhouse air temperature could be given by:

$$P_{sco} = 6894.76 \exp [51.59 - \frac{6834.3}{T_{co} + 273.15} - 5.17 \ln(T_{co} + 273.15) \quad (9)$$

$$P_{sp} = 6894.76 \exp [51.59 - \frac{6834.3}{T_{sp} + 273.15} - 5.17 \ln(T_{sp} + 273.15)] \quad (10)$$

$$P_{sst} = 6894.76 \exp [51.59 - \frac{6834.3}{T_{st} + 273.15} - 5.17 \ln(T_{st} + 273.15)] \quad (11)$$

$$P_{sgh} = 6894.76 \exp [51.59 - \frac{6834.3}{T_{gh} + 273.15} - 5.17 \ln(T_{gh} + 273.15)] \quad (12)$$

The actual vapour pressure in the greenhouse was determined by HORTITRANS model (Jolliet, 1994).

$$P_{gh} = \frac{\upsilon a I + h_t P_{sgh} + h_v P_{so}}{h_t + h_c + h_v} \quad (13)$$

The relative humidity inside the greenhouse can be determined by

$$\phi = \frac{P_{gh}}{P_{sgh}} \times 100 \quad (14)$$

$$a = c_1 \ln(1 + c_2 L_i^{c_3}) \quad (15)$$

$$h_t = c_4 L_i (1 - c_5 e^{(-I/c_6)}) \quad (16)$$

$$h_v = \rho_a C_{pa} \frac{q}{A} \quad (17)$$

Material for nursery bed preparation

Out of total 80 m^2 floor area, 55 m^2 area is used for plant seedling and 25 m^2 area is left for movement in the greenhouse carrying out agricultural operations. In 55 m^2 area of greenhouse, 9700 seedling could be raised with 0.075 × 0.075 m spacing in 20 pits. Each pit of size 2.75 × 1 m was filled with locally available garden soil, sand and vermicompost in 1:1:1 ratio. No chemical was used to control soil properties because moderate temperature was predicted inside the greenhouse. The hard-wood stem cuttings of about 20 to 25 cm (8 to 9 inch) long were prepared from one year old mature shoots. This was done by giving a slant cut at the basal portion about 1 cm below a bud and another round cut was made at the top 3 cm away from the bud. The cuttings were about 10 to 12 mm thickness. All cuttings were treated with rootex (Toky and Srinivasu, 1994) for 30 s and used for propagation on nursery beds inside the greenhouse.

Growth parameter

The different growth parameters such as number of cutting planted, sprouted, transferred, survival percentage, number of days required for sprouting, rooting and transplanting, number of leaves per seedling /cutting, height of plant and length of the longest root per seedling were observed.

Parameter of economic consideration

For the success and commercialization of this technology, different economic indicators were calculated for economic analysis of the arch shaped greenhouse in this study (Kothari and Panwar, 2004).

Net present worth

The mathematical statement for net present worth (NPW) can be written as:

$$\text{NPW} = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} \quad (18)$$

Where, Ct = Cost in each year, B_t = Benefit in each year, t = 1, 2, 3.....n and i = discount rate.

Benefit cost ratio

The mathematical benefit-cost ratio can be expressed as:

$$\text{Benefit-cost ratio} = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}} \quad (19)$$

Payback period

It shows the length of time between cumulative net cash outflow recovered in the form of yearly net cash inflows.

RESULTS AND DISCUSSION

Application of thermal model and values used in calculation are in Table 1. The maximum increase in greenhouse air temperature was 13.92°C for a solar radiation of 500 W/m^2 with 0°C ambient temperature (Figure 4). The above results indicate that under cold and sunny climate we could cultivate those crops inside the greenhouse which cannot be grown outside the greenhouse at low temperature.

It is clear from Figure 5 that difference in greenhouse air temperature is more with increasing solar radiation and decreasing ambient temperature while this difference is less with increasing solar radiation and ambient temperature (Cooper and Fuller, 1983). Cover temperature, soil temperature, plant temperature and greenhouse temperature are shown in Table 2.

Greenhouse air temperature

The increase in greenhouse air temperature above ambient temperature is up to 15°C more than ambient temperature during sunshine hours.

Cover temperature

Cover temperatures were found as lowest from 1 to 8 a.m. and increased with increasing ambient temperature and solar radiation up to 13 to 14 p.m.; and later on, decreased with decreasing ambient temperature and solar radiation.

Soil temperature

Trend of temperature changes for soil was also the same as cover temperature but slightly more than cover temperature.

Crop temperature

Changes were observed in the temperature of crop as an intermediate stage of cover temperature and soil temperature.

Experimental and calculated values of greenhouse temperature were almost the same with variation of 2 to 3°C (Figure 6). It may be inferred from these results that the theoretical values were in reasonably good agreement with the experimental results. Therefore, the mathematical model could be used to predict temperature conditions inside the greenhouse for a variety of climatic parameters.

Table 1. Specification and properties used for modeling.

Parameter	Values	Unit
Length of greenhouse (L)	13.4	meter
Thickness of polythene (Th_{pe})	200	micron
Absorptivity of cover (α_{co})	0.25	Dimensionless
Transmitivity of cover (τ_{co})	0.75	Dimensionless
Density of polythene (ρ_{pe})	1150	kg/m^3
Specific heat of cover (C_{co})	2302	J/kg °C
Emissivity of cover (ε_{co})	0.9	Dimensionless
Specific heat of air (Ca)	1005	J/kg °C
Thermal conductivity of air (Ka)	0.028	W/m^2 °C
Density of air (ρ_a)	1.2	Kg/m^3
Specific heat of plant (C_p)	3190	J/kg °C
Emissivity of plant (ε_p)	0.5	Dimensionless
Specific heat of soil (Cs)	2300	J/kg °C
Density of soil (ρ_s)	1250	Kg/m^3
Absorptivity of soil (α_s)	0.80	Dimensionless
Emissivity of soil (ε_s)	0.05	Dimensionless
Wind velocity (W)	5	Km/h
Area of ventilation (A_{vent})	0.09	m^2
Stefan-Boltsman constant (σ)	5.67×10^{-8}	W/m^2 K^4
Prandtl Number (Pr)	0.7	Dimensionless
Atmospheric pressure (P_{atm})	101.325	Kg/m^2

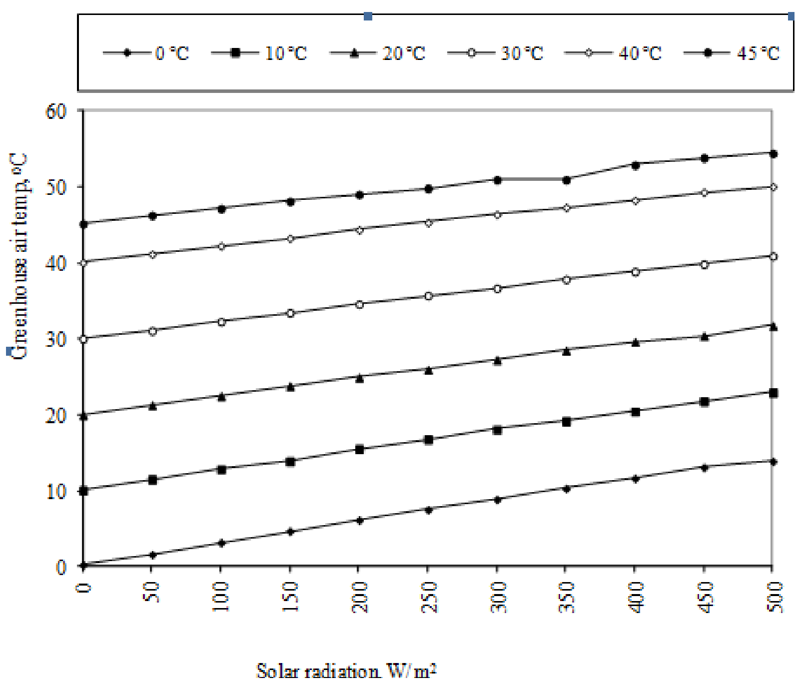

Figure 4. Greenhouse air temperature for different solar radiation and ambient temperature (°C).

Economic analysis of nursery

Based on the predicted environment inside the arch shaped greenhouse, the cuttings of Champa (*Plumeri* sp.) were selected for nursery raising. The different growth parameters observed are shown in Table 3. It

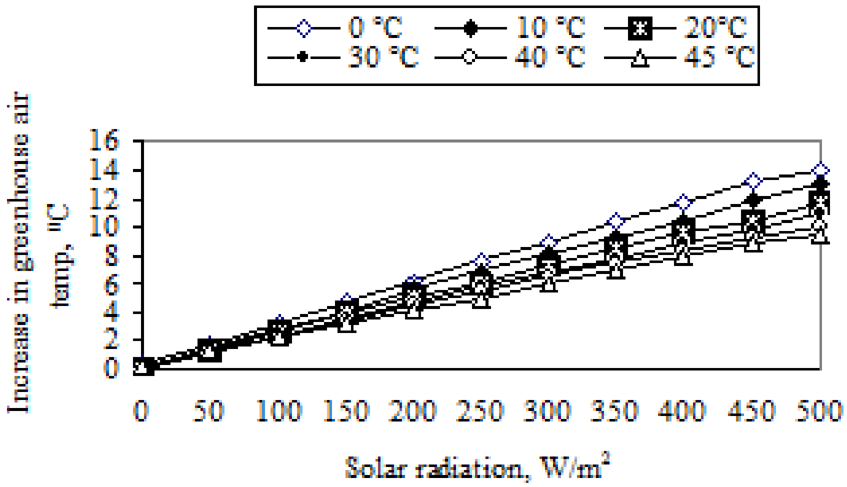

Figure 5. Increase in greenhouse air temperature with solar radiation.

Table 2. Hourly variation in greenhouse cover, floor, crop and greenhouse temperatures for the month of March at Udaipur.

Hour of the day	Ambient temperature (°C)	Solar radiation (W/m^2)	Cover temperature (°C)	Soil temperature (°C)	Crop temperature (°C)	Greenhouse temperature (°C)
1	15.5	0	20.4	20.65	20.53	20.53
2	14.9	0	20.7	20.94	20.82	20.8
3	14.4	0	20.11	20.35	20.23	20.21
4	13.7	0	19.61	19.86	19.73	19.7
5	13.3	0	18.92	19.17	19.04	19.02
6	12.8	1	18.52	18.78	18.65	18.63
7	17	65	18.06	18.34	18.2	18.29
8	18	259	19.47	21.15	20.36	20.57
9	20.3	473	24.89	29.64	27.43	27.55
10	22.8	653	31.76	39.04	35.63	35.58
11	24.9	778	37.02	45.96	41.74	41.58
12	26.3	842	40.74	50.58	45.9	45.66
13	27.2	844	42.72	52.85	48.01	47.72
14	33.2	769	43.21	53.08	48.36	48.02
15	28.1	635	42.24	51.2	46.92	46.58
16	27.9	458	40.1	47.59	44.03	43.68
17	27.6	249	36.74	42.2	39.62	39.31
18	26.4	64	33.01	36.05	34.62	34.39
19	24.5	1	29.35	30.46	29.95	29.8
20	22.9	0	26.49	26.74	26.63	26.56
21	21.8	0	24.87	25.1	24.99	24.94
22	21	0	23.78	24.01	23.9	23.86
23	20.2	0	22.98	23.22	23.1	23.07
24	18.4	0	22.19	22.42	22.31	22.23

shows that the whole process from propagation to transplanting is completed within two months inside the greenhouse. Table 4 shows the details of income and expenditure for *Plumeri* sp. nursery under greenhouse conditions. Selling price for Champa Rs 7/- per plant is based on average yearly price. Total benefit from the 80

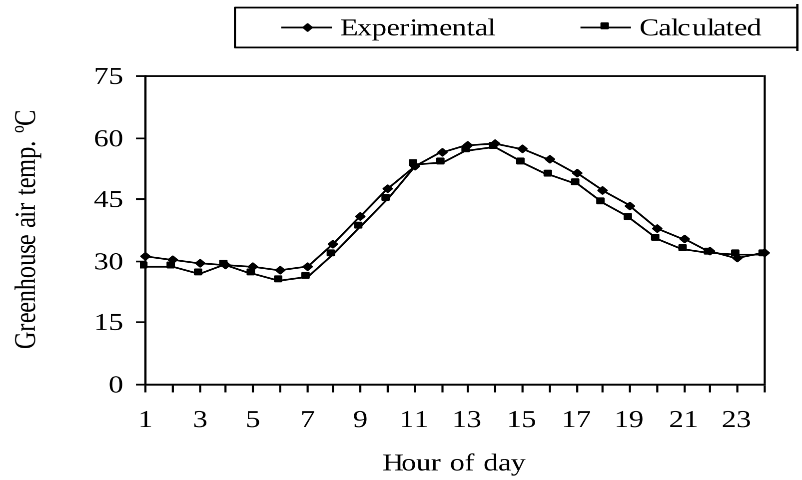

Figure 6. Comparison of theoretical and experimental values of greenhouse air temperature for the month of May at Udaipur.

Table 3. Overall growth parameter of *Plumeri sp.* plant inside the greenhouse.

Type of plants		*Plumeri* sp.
No. of days required for	Sprouting	20
	Rooting	40
Number of leaves after days	30	7
	60	15
Longest root after 60 days (cm)	Primary root	10
	Primary root	4
Days required for transplanting		60

Table 4. Details of income and expenditure for different crops under greenhouse conditions.

S/N	Particulars/ crops	Plant
1	Nursery plants	*Plumeri* sp.
2	No. of sprouted plants out of 9700	9215
3	No. of survival plants out of 9700	8642
4	Total Revenue(Rs)	60494
5	Common Cost for labour (Rs)	12400
6	Cost of cuttings(Rs)	2000
7	Cost of cultivation (Rs)	14400
8	Initial investment	100000
9	Cost of plastic every five year (Rs)	4000
10	Cost of electricity (Rs)	1200
11	Total operation and maintenance cost(Rs)	
	Every year	15600
	Every 5th year	19600

m^2 greenhouse was Rs. 44,894/- for three months, which could be sufficient for recovering the cost of greenhouse within 3.7 years; whereas net present worth and benefit cost ratio was Rs.3,54,822/- and 3.80 respectively (Table 5).

Table 5. Economic indicators for different plants in greenhouse conditions.

S/N	Economic Indicators	*Plumeri* sp.
1	NPW (Rs)	354822
2	B/C ratio	3.80
3	Payback period (years)	3.7

Conclusion

1. This model can be useful to predict the thermal environment inside the greenhouse for selection of plant nursery for different months, season and any location.
2. Difference of greenhouse air temperature is more with increasing solar radiation and decreasing ambient temperature while this difference is less with increasing solar radiation and ambient temperature.

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Nomenclature: **A,** Area, m^2; A_s, A_{co}, A_p, soil, cover and plant area; **C,** specific heat, J/kg °C; C_1-C_6, coefficient of equation; C_{pa} C_{pp}, specific heats of greenhouse air and plant; **h,** heat transfer coefficient, W/ m^2 °C; h_{ds}. mass transfer coefficient for floor; h_{rpco}, h_{rsco}, h_{rcosky}. Radiative heat transfer between plant to cover, soil to cover and cover to sky; h_{rpsky}. Radiative heat transfer between plant and sky; h_{pa}, h_{coa}, h_{coo}. convective heat transfer coefficients between crop and greenhouse air, cover and greenhouse air, cover and ambient; h_{sa}. convective heat transfer between floor and greenhouse air; h_{sg}, latent heat of evaporation, kJ/kg; h_t, coefficient of heat transfer for transpiration; h_v, coefficient of heat transfer for ventilation; I_s, I_p, I_{co}, solar radiation on soil, plant and cover; **k,** thermal conductivity of floor; **L,** length of greenhouse; L_i, leaf area index; m_h, mass flow rate out of cooling/ dehumidifying device; m_v, Mass flow rate due to natural or forced venting with ambient air; **Nu,** Nusalt number; **P,** vapour pressure of outside air; P_{gh}, vapour pressure inside greenhouse; P_{sco}, P_{dst}, P_{sc}, saturation vapour pressure at cover, floor and crop temperature; Q_{ap}, Q_{aco}, Q_{as}, energy absorbed by crop, cover and floor from solar radiation; Q_{bs}, energy transferred by conduction; Q_c, Energy transfer by condensation; Q_{cp}, Q_{cs}, Q_{cps}, Energy transfer by convection between plant, soil and plant and soil; Q_{cco}, Q_{ccs}, energy transfer by convection between cover and cover and soil; Q_h, Q_i, energy transfer due to cooling device and infiltration; Q_{pci}, Q_{pc}, Q_{ps}, energy transfer by convection between plant and infiltration, plant and soil and greenhouse air; Q_r, Q_{rs}, energy transfer by radiation between plant and ambient and between soil and plant; Q_{rpco}, Q_{rsco}, energy transfer by radiation between plant and cover and between soil and cover; Q_{rcosky}, Q_{rpsky}, energy transfer by radiation between cover and skay and plant and sky; Q_t, energy transfer by plant transpiration; Q_{tb}, energy transfer by conduction between top surface layer and main mass of soil; Q_{ve}, energy transfer due to ventilation with ambient air; Q_{vs}, energy transfer due to evaporation from soil; **R,** radius; **Re,** Reynolds number; **Tp,** plant temperature; **T,** thickness of soil; **Ttb, Tst,** temperature of toplayer of soil and temperature of top layer and soil sink; α_p, α_{co}, α_s plant, cover and floor absorbance; ε_p, , ε_{st} plant and floor emittance; **σ,** Stefan bolts man constant; **τ,** transmittance.

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