Automatic Microclimate Control in Greenhouses

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Abstract:
Agricultural production is to be increased by developing and adopting suitable technologies to ensure food security of the growing population. For a plant of given genetic makeup the factors that affect the plant growth are light, temperature, air composition and nature of the growing medium. Hence the crop growing environment is to be suitably modified to maximize production leading to optimum productivity. In the case of open field cultivation only the growing medium can be controlled, whereas in greenhouses all the environmental parameters can be suitably controlled or modified. We can cultivate any crop, anywhere during any season inside a greenhouse by modifying crop growing environment. Different microclimate parameters inside the greenhouse are to be precisely controlled for the successful greenhouse cultivation or to maximize production. Controlling can be done either by manually or by automatic control system which comprises measurement, data processing, recording and management of environmental parameters. Manual method of control is not accurate, very time consuming and very laborious process. Hence automatic control of microclimate is required for better performance of greenhouse. Different methods of automation of greenhouse include the use thermostats, microprocessor based control systems and computer controlled systems. Computerized control is more accurate but not economical for small/medium farmers. Microprocessor based control is good for small farmers.

Keywords: Green house, microclimate control, automation

I. Introduction
Agricultural production is to be increased to assure food security for the growing population. This can be achieved by developing and adopting technologies which can maximize agricultural production. For a plant of given genetic makeup the factors that affect the plant growth are light, temperature, air composition and nature of the growing medium. Hence the crop growing environment is to be suitably modified to maximize production leading to optimum productivity. The environmental factors to be modified include light, temperature, relative humidity, carbon dioxide concentration and nature of growing medium. In the case of open field cultivation only the growing medium can be controlled and the environmental factors which affect crop growth cannot be controlled manually, whereas in greenhouses all the environmental parameters can be suitably controlled or modified. We can cultivate any crop, anywhere during any season inside a greenhouse by modifying crop growing environment. Automatic regulation of crop growing environment is of great importance and most of the cultivators are unable to manage it manually. Greenhouses are framed or inflated structures covered with transparent or translucent material, in which crops can be grown under the conditions of at least partially controlled environment and are large enough to allow a person to walk within them to carry out agricultural operations. A greenhouse protects plants from wind, precipitation, excess solar radiation, temperature extremes, pests and diseases.

II. Advantages of growing plants in greenhouses
a. Productivity per unit area can be increased because the genetic potentiality can be fully exploited
b. Intensity of cropping can be increased
c. Any crop can be grown any where during any season of the year depending on the demand from the market
d. Problematic area can be brought under cultivation
e. Excellent quality produce can be obtained
f. Higher extent of bud or graft take
g. Easy protection from pests and diseases
h. Temporary storage
i. Controlled environment research work in horticultural crops is possible
j. The produce can be obtained early in the season, with minimum requirement of water (Attavar, 1997).

2. Microclimate control in greenhouses
Covering material of greenhouse is acting as a barrier between greenhouse microclimate and ambient climate. The presence of greenhouse cover causes changes in the microclimatic condition as compared to that of outside by reducing radiation and air velocity, by increasing temperature and vapour pressure of the air and by making the fluctuations in carbon dioxide concentrations. Each of these changes has its own impact on growth, production and quality of the greenhouse crop, some of them being detrimental and hence greenhouse microclimatic conditions are to be modified based on crops to be cultivated and ambient climate.

2.1 Light
Light may be considered as the most important environmental factor in greenhouse cultivation, as it influences a wide range of processes related to photosynthesis, energy balances including transpiration, phase transitions and morphology. In general low light intensity is the most important environmental restraint to maximum photosynthesis and growth. The opening and closure of stomata, thereby the transpiration is affected by light intensity. In order to achieve good growth of plants inside the greenhouse, there should be sunshine of desired quantity and intensity.
2.2 Temperature
Temperature control in greenhouses is necessary for optimum growth and development of plants. It influences initiation and development of reproductive organs. Temperature manipulation to induce flowering has commercial value in horticulture. Temperature affects time from sowing to flowering in three distinct ways: (1) there may be a specific cold temperature hardening of flowering (2) the rate of progress towards flowering increases with increase in temperature to an optimum level at which flowering is most rapid and (3) at supra-optimal flowering is progressively delayed as temperature gets warmer. When outdoor temperatures are too low, it is relatively easy to maintain temperature within desired limits in greenhouses. Heat can be added through the heating system or it can be removed by natural ventilation. However as seasonal temperatures increase, precise control of day temperature becomes more difficult. It generally requires forced ventilation evaporative cooling to control excess temperature.

2.3 Relative Humidity
Greenhouse is an enclosed space and hence the relative humidity inside the greenhouse will be more compared to ambient air due to the moisture added by evapotranspiration process. Ventilation and sensible heat inputs lowers the relative humidity to some extent. For the purpose of maintaining relative humidity levels, evaporative cooling is employed for humidification and if relative humidity is on the higher side, ventilators, chemical dehumidifiers and cooling coils are used for dehumidification. For most of the crops, the acceptable range of relative humidity is between 50 to 80% and for plant propagation work relative humidity up to 90% may be desirable (Manohar and Igathinathen, 2012).

2.4 Carbon Dioxide
Carbon is an essential plant nutrient and carbon dioxide gas in the air is the important source of carbon to plants. About 40% of dry matter of plants is composed of carbon. Normally percentage of carbon dioxide in atmosphere is 0.03% (345 ppm). Within the greenhouse as plants uses carbon dioxide for photosynthesis, its concentration decreases in the case of fully closed greenhouses and the level is to be increased either through ventilation or through artificial methods. The plant growth will be retarded if carbon dioxide concentration is less than ambient level. The requirement of carbon dioxide depends on crop species, light, temperature, nutrient level and degree of maturity. Most of the crops have a favourable response to carbon dioxide concentrations at the level of 1000 to 1200 ppm (Manohar and Igathinathen, 2012).

2.5 Greenhouse Cooling
Greenhouse temperature is very high when compared to ambient condition and reducing inside temperature is one of the main problems facing greenhouse management. Cooling is more expensive and more difficult than heating. Techniques of greenhouse cooling based on convection/forced air movement are

- Roof shading
- Ventilation with roof and side ventilators
- Forced ventilation using fans
- Maintaining water film on greenhouse covering material
- And Evaporative cooling

Energy balance equation for greenhouse air can be written as

\[ E_{\text{Rin}} + E_{\text{H1l}} = E_{\text{Vent}} + E_{\text{ET}} + E_{\text{EC}} \]

Heat energy inside the greenhouse

Where,

- \( E_{\text{Rin}} \) = Solar energy transmitted to and absorbed in the greenhouse
- \( E_{\text{H1l}} \) = Heat transferred by conduction and convection to the greenhouse air through the cover and sides
- \( E_{\text{Vent}} \) = Energy transferred out of the greenhouse through Ventilation
- \( E_{\text{ET}} \) = Energy used for Evapotranspiration by the crop
- \( E_{\text{EC}} \) = Energy consumed to evaporate water by the evaporative cooling devices

A change in any one of these factors affects other factors. For example if we reduce solar radiation by means of shading, photosynthesis and transpiration usually decreases and the ventilation rate is changed by the change in temperature. Greenhouses can be cooled by any of the methods commonly used in commercial, industrial or residential buildings. But the large cooling loads imposed on greenhouses by the sun and the high costs of installing and operating air conditioning systems reduce the practical options for cooling greenhouses to ventilation, evaporative cooling and shading. Ventilation may be used with or without evaporative cooling but evaporative cooling cannot be used without ventilation (Albright, 1997).

2.5.1 Ventilation of Greenhouses
Ventilation of greenhouses is the process of exchanging air inside the greenhouse with the outside air. Ventilation required to remove surplus solar heat, evaporated and transpired water vapour and for supply of carbon dioxide. Ventilation rate is the volume of air exchange per unit of time per unit floor area. Sixty air changes per hour necessary to avoid heating above the outside air temperature (Walker1965).

2.5.1.1 Natural Ventilation
In this system, the movement of inside air takes place due to pressure difference created by wind or temperature gradients. According to Kozai and Sase (1978) for outside wind velocities less than 2 m/s, the number of air changes was mainly dependent upon the inside to outside temperature difference. Above 2 m/s, the number of air changes proportional to wind speed. Bakker (1984) reported that as ventilation area increased from 0 to 60% for a cucumber cultivated greenhouse, water vapour transport by ventilation increased from 1 to 28 g/m²/min and transpiration increased from 3 to 12 g/m²/min. This shows that there is close relation between water vapour transport and transpiration. Papadakis et al. (1996) reported that air exchange rate depends on wind velocity and ventilator opening area and not on wind direction. Effect of humidity on air exchange is less compared to temperature (Albright, 1997). Presence of crop decreases ventilation efficiency (Boulard et al., 1997). Baeza et al. (2012) reported that air exchange rates per unit ground area were highest when the distance between sidewalls equipped with vents was small.

2.5.1.2 Forced ventilation system
When high ventilation rates are required, then forced ventilation will be used to exchange air from greenhouse to outside. Forced ventilation is of two types
Ventilation fans for air exchange (most commonly used)

Fans for internal air mixing to improve air temperature uniformity and to keep the carbon dioxide concentration within dense plant canopies up to the ambient level. Adequate air flow is the first requirement for any cooling system. It is a good practice to arrange the fan systems to operate in two to four stages so that air flow can be matched to the cooling requirement at any given time. With exhaust fans, temperature within a fully cropped greenhouse will not exceed more than three to five degrees hotter than that of outside (Mears, 1991).

2.5.2 Evaporative cooling

As water evaporates heat is absorbed and this is the principle of evaporative cooling. The degree of cooling obtained from an evaporative cooling system is directly related to the wet bulb depression that occurs with a given set of climatic conditions. The evaporative cooling systems used in greenhouses are fan and pad system and mist or fog system. Evaporative cooling systems are more effective in areas where low humidity exists. Generally the lowest humidity occurs during the hottest part of the day and at that time the greatest degree of cooling required and evaporative cooling is more effective. During night, relative humidity increases and temperature decreases. The efficiency of evaporative cooling is at its lowest during the night (Rajinder, 1985).

2.5.2.1 Fan and pad cooling system

It is a mode of evaporative cooling in which the warm air from greenhouse is removed by the exhaust fans and the cool air is brought in through the wetted pads placed vertically along one wall of the greenhouse. Water is allowed to pass through the pads when exhaust fans works for the operation of the system. The area of pads provided has a greater effect of cooling.

2.5.2.2 Fog cooling system

Fog evaporative cooling system uses high pressure pumping apparatus to produce extremely fine mist, allowing essentially a fog that tends to remain in the air. Evaporative cooling occurs above the crop with minimal wetting foliage. A heavy fog also reduces solar intensity. Such a system is expensive, requires heavy pumps, pipe fittings, special nozzles, and very clean water and it has a high electrical consumption. Ultra-fine droplets of water fill the greenhouse atmosphere and cool the greenhouse as water evaporates. Main advantage of fog system compared to fan and pad systems are the uniformity of conditions throughout the greenhouse and it can lower the greenhouse temperature to wet bulb temperature (Montero and Anton 1994).

2.5.3 Roof shading

The amount of solar radiant energy entering the greenhouse can be reduced by providing shade over the greenhouse cover or by applying opaque materials directly over the greenhouse cover. Commercial shading compounds or mixtures prepared with paint pigments are preferred for this purpose. White compounds are preferred as they reflect maximum amount of sunlight. Shading compound are less effective than shade covers. Shading compounds reflects most of the radiant energy, but some of it is absorbed and transmitted to the inside by conduction, but for the latent heat, air circulates between laths and cover and hence it provides more cooling. Another method of shading is to install curtains of various cloth materials on the greenhouse (Rajinder, 1985).

III. Automatic microclimate control in greenhouses

Different microclimate parameters inside the greenhouse are to be precisely controlled for the successful greenhouse cultivation or to maximize production. Controlling can be done either by manually or by automatically. Manual method of control is very time consuming and very laborious process. Hence automatic control of microclimate is required for better performance of greenhouse. Greenhouse crop production is based on a controlled environment to provide the necessary conditions that are most favourable for maximum crop yield. Optimization of the greenhouse environment is achieved by controlling atmospheric as well as soil factors to the required level of the particular crop. Atmospheric parameters include air temperature, solar radiation, relative humidity, air composition and air velocity and soil parameters include soil temperature, soil moisture, soil pH, nutrient status and soil physical, chemical and biological parameters. Greenhouse environmental conditions are managed by manual or automatic control system which comprises measurement, data processing, recording and management of environmental parameters. Development of an automated greenhouse system that is low cost, operates with minimum human intervention, accurately able to maintain its set points, able to learn and adjust itself have been some of the very obvious interests in which investigators are working to fulfill economic, environmental, market, industrial and human preference needs (Salokhe and Sharma, 2012).

3.1 Thermostats

Thermostat is a device for sensing temperature and for activating/deactivating the attached equipment with reference to a set of temperature thermostat is made by either a bimetallic strip or thin metal tube filled with fluid as sensor and it will produce some physical displacement corresponding to the temperature. These sensors activate a mechanical switch by differential expansion of bimetallic strip or by movement of tube due to change in the volume of fluid. The main disadvantage is its less accuracy (Manohar and Igathinathen, 2012).

3.2 Microprocessor

Microprocessors considered as simple computers can be used for more accurate management of greenhouse microclimate than thermostats. Microprocessor has a keypad, LCD screen, indicators and provision for input and output connections. They can control many devices at a time based on input parameters. They receive signals from sensors for temperature, relative humidity, light intensity, wind speed etc. and operate different microclimate control devices such as ventilators, fans, evaporative cooling system etc. Microprocessor mostly uses thermistor or thermocouple as temperature sensors. Thermistor is a solid state integrated circuit chip that changes the output voltage according to temperature change. A thermocouple consists of two dissimilar metallic wires joined together to form two junctions. One junction connects to the place where temperature is to be measured and the other end is to be connected to the surface having reference temperature. Thus the thermocouple measures unknown temperature, based on known temperature of reference body. An electronic circuit connects sensors to microprocessor and to different instruments such as fans evaporative cooling system etc. through a relay. Wanget al. (2008) developed a multi-channel system for simultaneous monitoring of multiple environmental factors and electrical signals in cucumber.
plants in the greenhouse. The system includes a special sensor, which is both sensitive and reliable for long-term use for collecting electrical signals. Using this system, they proved that the electrical signals in plants respond to environmental changes under natural conditions in the greenhouse. The system could provide a long-term stable tool to measure and analyze the electrical signals in plants in greenhouses. Dondapati and Rajulu (2012) designed a sensor based automation system for greenhouse. This is capable of managing the greenhouse without any human interference. Based on real time data collection from different sensors, it is capable of controlling the greenhouse microclimate by operating foggers, fans, irrigation system and lighting system. Real time display of microclimatic data on liquid crystal display screen helps the greenhouse technicians to know the exact environmental parameters in it. The system consists of different sensors for collecting data, analogue to digital converter, microcontroller and actuators. Threshold values of microclimatic parameters can be set according to the crops to be cultivated and when any of the parameters exceed the threshold value, the microcontroller actuates the required equipment to maintain favourable environment for crop growth. Experimental results show that the system performance is good for managing greenhouses.

3.3 Computer controlled systems

This is the higher end method of microclimate control in greenhouses and mostly used in developed countries. Computer controlled systems can integrate the parameters from different sensors and precise control of the microclimate is possible through this system. Based on the programme used, the computer will activate or deactivate the different control devices, ventilators, shading devices, fans etc. based on input parameters such as inside and outside temperature, humidity, outside wind condition, inside carbon dioxide concentration etc. Computer receives signals from all sensors, evaluates all conditions and it will operate different equipment based on the crop inside the greenhouse. Computer also record the data received and which will be very useful information in precision farming because this data will provide comprehensive knowledge of all factors affecting the quality and quantity of product.

Advantages of computerized control include

- As computers control precisely, there will be saving of inputs and energy and chance of pest and disease attack will be less in computer controlled systems.
- With the help of a good programme, computer will coordinate all the equipment for microclimate control.
- The computer can record and store environmental data which will provide a history of cropping period.
- A single computer can manage many greenhouses if programmed and managed.

Disadvantages include

- High initial investment required.
- Requires qualified technicians for operation and maintenance
- High maintenance cost
- Not economical for small and medium scale farmers.

Junxiang and Haiqing (2011) designed a greenhouse surveillance system based on embedded web server technology. Based on ARM-Linux development environment, they constructed embedded web server and use it in acquisition and transmission of greenhouse information. Experiment results show that the working performance of the system is quite stable and can reach the design requirements in real-time data acquisition and remote control. Khandelwal (2012) developed GSM modem based automation system to control greenhouse microclimate. The system consists of various sensors to collect information about greenhouse temperature, relative humidity, light intensity, rain sensors and transistor switches and relay nodes for automation control. There is a data server to store the information about the environmental conditions inside the greenhouse. Based on the requirement of crop, automation system will maintain required environmental conditions for crop growth. Matrinovic and Simon (2014) developed a mobile measuring station for greenhouse microclimate control. They used wireless sensor networks (WSN) for gathering and monitoring microclimate parameters both inside and outside the greenhouse. They fitted the sensors on a robot and navigation of robot done through WSN. From the starting point, the mobile robot should find a path to the target in a dynamic environment, avoiding any obstacles. They also developed an expert system to control the various environment control equipment attached to the greenhouse based on the collected data. The expert system is a multi-criteria decision making based on application of fuzzy rules. They developed six control strategies for managing greenhouse microclimate based on sensed values of different parameters. Six control strategies were developed: STR1 – Day High Performance, STR2 – Day Normal, STR3 – Day Economic, STR4 – Night High Performance, STR5 – Night Normal, STR6 – Night Economic. The best control strategy will be selected based on input parameters. The schematic diagram shown in Fig.3 and hierarchy for selection of control
strategy shown in Fig.4. Experimental results shown in Fig.5 and Table 1. From results it is clear that greenhouse control system is working in a good manner.

![Image](image1.png)

**Fig.3 Schematic diagram**

店里: Matrinovic and Simon (2014)

Table 1 Average total weight and the number of fruit harvested.

<table>
<thead>
<tr>
<th>Tested plants</th>
<th>Average weight of fruit (with automation)</th>
<th>Average weight of fruit (without automation)</th>
<th>Average number of fruit per plant (with automation)</th>
<th>Average number of fruit per plant (without automation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomato</td>
<td>215 g</td>
<td>185 g</td>
<td>18</td>
<td>11</td>
</tr>
<tr>
<td>Capsicum</td>
<td>140g</td>
<td>120g</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>Cucumber</td>
<td>80g</td>
<td>60g</td>
<td>15</td>
<td>12</td>
</tr>
</tbody>
</table>

Source: Matrinovic and Simon (2014)

**Fig.4 A hierarchy for the selection of the control strategy**

IV. Conclusions

Microclimate control is necessary and according to crops to be cultivated and ambient climatic conditions, suitable methods can be adopted. Automatic climatic control is required for better management of greenhouses. Computerized control is more accurate but not economical for small/medium farmers. Microprocessor based control is good for small farmers.

V. References


