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RESEARCH ARTICLE

PERFORMANCE OF A LOW COST AUTOMATION SYSTEM FOR GREENHOUSE COOLING

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ABSTRACT

The Land available for cultivation is decreasing and population is increasing. This necessitates the requirement of adopting scientific methods for achieving maximum production. Maximum yield from crops can be achieved by proving required quantity of nutrients and water and also the desired level of microclimate. Microclimate modification is possible in greenhouses and this is the advantage of greenhouse cultivation compared to open field cultivation. Greenhouse cultivation requires microclimate management as well as application of water and nutrients to plants daily. This requires labour and this cost can be reduced by adopting automation systems. This paper presents a performance study of a locally developed low cost automation system on greenhouse cooling. Temperature inside the greenhouse is to be reduced in summer in Kerala which falls under humid tropical climate. The automation system installed in one greenhouse and temperature recorded at hourly intervals. Temperature measurements were taken from another greenhouse which is manually controlled. Saniya variety of salad cucumber was cultivated in both the greenhouses. Temperature data and crop data from both the greenhouses collected and compared. Performance of the automation system was good in controlling the greenhouses temperature. Yield obtained from greenhouse operated by automation system was higher compared to other.

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INTRODUCTION

Food security of the exponentially growing population can only be met through the application of suitable technologies which can maximize agricultural production. 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.

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We can cultivate any cop, 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. Greenhouse is a type of protected cultivation which is used for protection of plants from wind, precipitation, excess solar radiation, temperature extremes, pests and diseases. 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. Advantages of growing plants in greenhouses include; maximum production per unit area, increasing intensity of cropping, cultivation of any crop anywhere during any season of the year depending on the demand from the market, cultivation of problematic areas, better planting material production, better protection from pests etc. The covering material causes the greenhouse microclimate different than outside climate. Because of the covering material greenhouse effect occurred in greenhouse and this increases the temperature inside the greenhouse.

Light intensity inside the greenhouse is reduced inside the greenhouse. Relative humidity, air velocity and carbon dioxide concentration inside the greenhouse is also different than outside. Hence the growth and yield from greenhouse is also different than outside. Every crop has its own microclimate range in which maximum amount of production obtained. 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 hastening 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 or evaporative cooling or both to control excess temperature (Manohar and Igathinathen, 2012). For greenhouse cooling several methods are used in greenhouses such as roof shading, ventilation with roof and side ventilators, forced ventilation using fans, maintaining water film on greenhouse covering material and evaporative cooling. While using evaporative cooling ventilation also is required. Otherwise relative humidity inside the greenhouse will be increased and this causes crop damage (Albright, 1997). 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).

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). 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). Cooling of the greenhouse can either be done by manually or it can be done automatically. Manual method of temperature control is labour consuming and also real time temperature control is not possible manually. Hence automatic temperature control is required. This paper describes the comparative evaluation of a manually controlled greenhouse.

REVIEW OF LITERATURE

Some of the important previous research works related to the paper are given below Helmer *et al*. 2005 developed Crop Assist, an automation system for direct measurement of greenhouse tomato growth and water use. The system used pairs of load cells and a trough system to capture crop growth and water use, and many irrigation parameters may be measured simultaneously. The system concurrently monitors four sites, with up to 12 plants each, but is expandable as needed with more sites strategically placed in the greenhouse.

Wang *et 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. Ehret *et al.* (2011) developed a neural network model that can be used to find out the greenhouse tomato growth and yield and water use from the automatic monitoring of greenhouse crop attributes. The automated measuring device takes continuous minute by minute measurement of crop yield, growth and water use and also gives average values of hourly, daily,, weekly or monthly. The data collected from automated crop monitoring station is used in the neural network model to predict crop attributes. They related the environment data crop yield and also the weekly growth and yield of next week. 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.

Dondapati and Rajulu (2012) developed and tested an automation system for greenhouses. The test results proved that better environment control obtained through the automation system. The automation system manages based on the sensed environmental parameters. If the threshold value of parameters exceeded, the automation operated the actuators.

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. The sensed values send to the server. They developed programme and installed in server for the greenhouse management. Based on the preset threshold values the automation system operated the actuators and thus greenhouse environment was managed.

Kaur and Kumar (2013) developed a micro controller based fertigation automation system. The system includes sensors for measurement of EC and pH of fertilizer solution and soil and a micro controller for the control of the system. Based on the sensed value of EC and pH of soil microcontroller will be activated to get required amount of fertilizers in the mixing tank and thus required amount of fertilizer can be applied to plants.

Iacomi *et al.* (2014) developed a computer controlled system for precise application of water, fertilizer and pesticides. The system consists of a data acquisition unit, a central processing unit and a driving unit. The collected from soil and plant through sensors peovided and this data is sent to central processing unit. The embedded software process the data and based on that required quantity of water and chemicals will be applied. The system thus reduces the use of inputs required for plants and leads to profit. More over it was an environment friendly approach.

Jinu and Hakkim (2016) presented a brief review of the different microclimate control systems. Different types of automation systems used for greenhouse cooling were discussed in this paper.

Pawlowski *et al.* (2017) developed and tested automation system for greenhouses. They reported that 20% saving in water obtained through this system.

Sunny and Hakkim (2017) reported about a solar powered fertigation automation system. The field trial was conducted in a greenhouse in Kerala and found that automatic fertigation gives more yield compared to manual method of fertilizer application.

MATERIALS AND METHODS

The experiment was conducted at Agricultural Research station, Anakkayam, which is a research station under Kerala Agricultural University. The automation system was developed using logical circuits. The important components of the automation system include controller, temperature sensor, humidity sensor, exhaust fans, foggers, relays, transformers, voltage regulators, rectifiers, solenoid valves, timer, bubblers, fertilizer injection pumps, fertilizer tanks, and water lever indictors. Based on the input signals from temperature and humidity sensors, the microcontroller activates the exhaust fans or foggers along with exhaust fans. Microcontroller is the main part of the automation system. Threshold values of temperature and relative humidity can be set in the controller. This is a microprocessor which can be considered as a simple computer. Based on the programme installed in it, the management operations of greenhouses are conducted. Exhaust fans and foggers were the actuators for greenhouse cooling. These were operated by the automation system based on the temperature and relative humidity values. Exhaust fans will be operated whenever the temperature is above the set value. If the relative humidity inside the greenhouse at that time is below the maximum level set in the controller, foggers also worked along with exhaust fans. Otherwise exhaust fans alone will be worked until the relative humidity inside the greenhouse becomes less than the upper level of relative humidity value set in the controller. Temperature differential of 1^0C and relative humidity differential of 5% set in the controller. This is for protection of the system. Maximum temperature set for this particular study was 37^0C and relative humidity as 65% and a differential of 5%. So when the temperature goes above so the relative humidity inside the greenhouse never exceeds above 70%. Within that limit of relative humidity, temperature inside the greenhouse was maintained by the automation system. Performance of the automation system for temperature control was studied by comparing the temperature data from greenhouse having automation system and another greenhouse which does not have automation system. Salad cucumber crop variety Saniya was cultivated inside the greenhouse and the performance of the crop also studied. Temperature data was collected from 10 am to 5 pm at hourly intervals. This data was collected from the greenhouse in which automation system installed and from the other one which was operated manually. Hourly temperature data from outside also was collected for the comparison. Performance of the crop inside both the greenhouses was studied by collecting and comparing biometric as well as yield parameters. Greenhouse in which automation system installed is taken as Treatment 1(T_1) and other greenhouse is taken as Treatment2 (T_2).

The performance of the crop was evaluated for a period of 90 days after transplanting. The seeds sown in portray and after one week it was transplanted inside the greenhouses. The plants transplanted in poly bags inside both the greenhouses on the same day. The crop inside both the greenhouses was irrigated at four times in a day. Fertigation was done once in three days, automatically in the first greenhouse in which automation system installed and manually in the other one which is annually operated. Split doses of fertilizer application were done. The requirement of fertilizer was calculated based on the recommendation by the package of practices, Kerala, published by Kerala Agricultural University and multiplying it with the number of plants, the total requirement of fertilizer was calculated. From which fertilizer requirement of one plant was calculated. The biometric and yield observations were collected from the selected fourteen plants from each greenhouse and compared.

One way ANOVA test was conducted for the comparison of the mean values of the data. The temperature data as well as crop data were undergone statistical analysis.

RESULTS AND DISCUSSION

The data collected from both the greenhouses were compared. Fig. 1 shows the hourly temperature variation of the automated greenhouse, non automated greenhouse and outside condition. From the graph it is clear that automated greenhouse was more capable of reducing temperature inside the greenhouse. The curve of automated greenhouse lies nearer to that of outside the greenhouse. Temperature curve of non automated greenhouse lies above that especially during hottest part of the day. The temperature inside the manually operated greenhouse increased up to 43.1^{0}C while in automated greenhouse it increased only up to 37.6^{0}C. This shows that better temperature management was done inside the automated greenhouse.

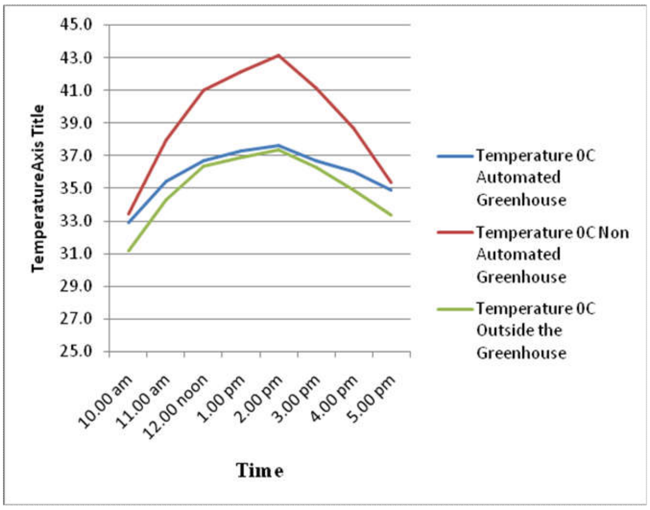

Figure 1. Hourly variation of temperature

Table 1 gives the mean values of temperature inside the greenhouses and outside. Mean value of temperature inside automated greenhouse was 35.9^{0}C while in non automated greenhouse it was 39.1^{0}C. Mean temperature outside was 35.1^{0}C. One way ANOVA conducted for the data to compare means and found that there was significant difference of temperature between automated greenhouse and non automated greenhouse but there was no significant difference of temperature between automated greenhouse and outside temperature.

Table 1. Mean values of temperature from 10 am to 5 pm

Treatments	*Temperature^{0}C
Automated Greenhouse	35.9^a
Non Automated Greenhouse	39.1^b
Outside the greenhouse	35.1^a

*Values followed by same letters are not significantly different at P<0.05

Evaporative cooling was the cooling method used inside the greenhouses. During evaporative cooling heat energy inside the greenhouse was used for the evaporation. Thus the temperature inside the greenhouse was decreasing. Through evaporative cooling temperature inside greenhouse can be reduced up to wet bulb temperature. If the relative humidity inside the greenhouse is less, then better evaporation and cooling results. On the other hand if the relative humidity is very high, then further evaporation and cooling will not happen. The automation system switches on the exhaust fans if the relative humidity is higher than upper threshold level, then water vapour along with moist air escapes from the greenhouse and at the same time outside air which is having lower value of humidity enter into the greenhouse. Thus relative humidity inside the greenhouse lowers and then foggers also will be switched on by the automation system. Hence better cooling observed inside the automated greenhouse compared to manually operated greenhouse. The important events of crop such as first flower bud formation first flowering, first fruit formation was observed earlier in automated greenhouse compared to manually operated greenhouse. Number of days after transplanting required for important events is given Table 2. Date of occurrence of first flower was 21 days after transplanting in case of automated greenhouse while in manually operated greenhouse it was 24. That is before 3 days first flower occurred in automated greenhouse compared to other one. First fruit formed 23 days after transplanting in automated greenhouse while in manually operated greenhouse it required 27 days. That is 4 days additionally required in manually operated greenhouse. 32 days after transplanting first harvest was done in automated greenhouse while in manually operated greenhouse it required 36 days. All these proved that automation system was better for the greenhouse cooling.

Table 2. Number of days require after transplanting for important events

Events	No. of days after transplanting	
	Automated Greenhouse	Manually operated greenhouse
First Flower formation	21	24
50% flowering	24	27
First fruit	23	27
First harvest	32	36

Table 3. Effect of treatments on height of plants

Treatments	*Height of plants (cm) during			
	First week	Second week	Third week	Fourth week
Automated greenhouse	20.4^a	79.6^a	161.5^a	276.1^a
Non automated greenhouse	18.6^a	59.4^b	134.9^b	238.3^b

*Values followed by same letters are not significantly different at P<0.05

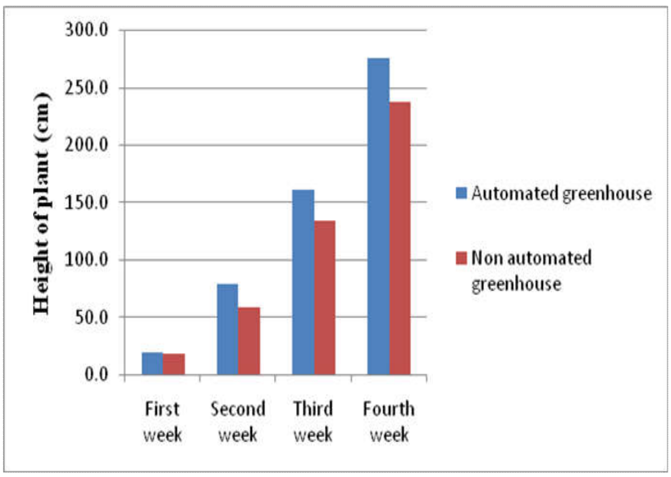

Figure 2. Effect of treatments on heights of plants

Weekly observation on height of selected fourteen plants each from the automated greenhouse and manually operated greenhouse was taken.

Table 3 gives the mean values of the observations on height of plants. This compared in Figure 2 and using one ANOVA test. There was no significant difference in plant height during the first week, but after that during the second, third and fourth weeks, there was significant difference in plant height between treatments. Comparison of the yield from automated and manually operated greenhouse is shown in Figure 3.

Average yield from the treatments are given in Table 4. Yield from the automated greenhouse was 7.54 kg/plant while from manually operated greenhouse it was 2.16 kg/plant. Mean comparison of treatments was done by one way ANOVA test and showed that there was significant difference in yield between automated greenhouse and manually operated greenhouse. In automated greenhouse temperature was maintained within the desirable level of the crop, but manually operated greenhouse it increased to higher level of above 43^0C during peak time. In automated greenhouse, temperature was managed based on the temperature relative humidity level inside the greenhouse. But in manually operated greenhouse, foggers and fans were operated for 5 minutes and then switched off for next 25 minutes and this repeated in every half an hour from 10 am to 5 pm. Superior temperature management was by automation system. The results proved that automatic temperature control was better for cultivation inside the greenhouse.

Table 4. Effect of treatments on the yield of cucumber

Treatments	*Yield kg/plant
Automated Greenhouse	7.54^a
Non automated Greenhouse	2.16^b

*Values followed by same letters are not significantly different at P<0.05

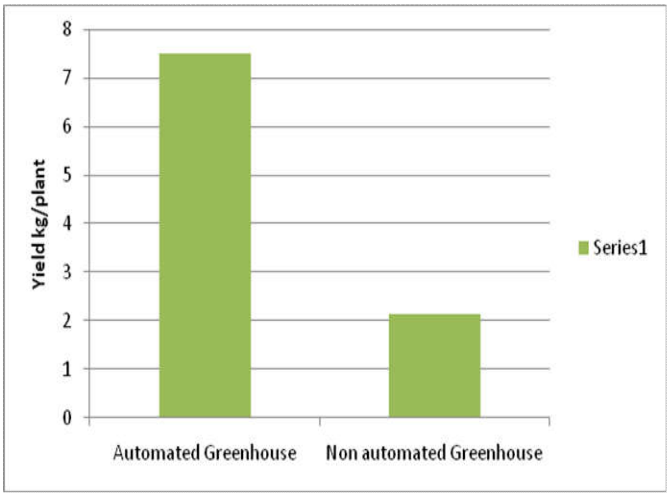

Figure 3. Comparison of yield from the treatments

Conclusion

From the observations and statistical analysis of the data collected, it was found that greenhouse installed with automation system provided better cooling compared to manually controlled greenhouse. Automation system reduced the mean temperature 3^0C less than that of manual method. The height of plants was higher in automated greenhouse. Greater yield obtained through the automatic temperature control. Important plant events such as first flower formation, first fruit formation and first harvest were earlier in automated greenhouse compares to other one. All these results indicate it is better to automatically control temperature inside the greenhouse.

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