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The Effect of Shape and Orientation on a Greenhouse: A Review

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Abstract

Greenhouse is a feasible option for sustainable crop production in the regions of adverse climatic conditions. For a successful greenhouse design, the selection of shape and orientation is of paramount importance. The relevance of this paper is to present a comprehensive and/or detailed review on the selection of shapes and orientation of a greenhouse for both cold and *composite climates. A detailed research showed that apart from orientation and shape, studies on design parameters, covering materials, cooling & heating technologies of a greenhouse are necessary to achieve desired benefit. Analysis of earlier studies show that uneven-span shape greenhouse receives the maximum solar radiation and quonset receives the minimum solar radiation during each month of the year at all latitudes and east-west orientation is the best suited for year round greenhouse application at all latitudes as this orientation receives greater total radiation in winter and less in summer except near the equator.*

Introduction

As a result of the changing conditions of the environment, protected cultivation in greenhouse has been the favoured way to develop the agricultural sector. Greenhouse is a structure, which provides a suitable environment for the intensive production of various crops. They are designed to provide control of solar radiation, temperature and carbon dioxide levels in the aerial environment thus providing the most suitable climate for maximum plant growth during off-season. Total solar radiation received by a greenhouse at a particular time and location depends upon its shape as well as orientation which ultimately determine the most dominant parameter affecting plant growth (inside air temperature)[1].

Earlier studies have shown that researchers have utilized different greenhouse shapes along different orientations to achieve a breakthrough in the agriculture production technology. Sethi [1] reported that an even-span, N-S orientation greenhouse of 309.7m^2 floor area was constructed (made of wood & cane) and situated in Coronda, Argentina. The commercial greenhouse was used to grow vegetables and covered with polyethylene film and was equipped with earth–to–air heat exchanger system. A vinery type high tunnel greenhouse (E-W orientation) located at Israel was used for raising winter vegetables. The greenhouse was covered with double layer polyethene sheet and was having side continuous vents for natural ventilation in summers [18].

In general, the selection of the best shape and optimum orientation of a greenhouse for different times of year and climatic zones cannot be neglected because it directly affects greenhouse inside air temperature. In this paper, an effort has been made to critically review the selection of the most suitable shape and orientation of a greenhouse for different climatic zones on the basis of total solar radiation availability and its effect on greenhouse inside air temperature. This information will be useful for agriculturist (farmers) who desire healthy plant growth and maximum yield during off-season.

Method

Design

Greenhouses are frames of inflated structure covered with a transparent material in which crops are grown under controlled environment conditions. Greenhouse cultivation as well as other modes of controlled environment cultivation have been evolved to create favourable micro-climates, which favours the crop production could be possible all through the year or part of the year as required. Greenhouses are constructed with a principle that they have a rigid load-bearing frame which is placed at certain spans and not deformed under the loads acting on them, and a transparent cover material placed on them. Most of the designs of greenhouses are done through strength of material analysis. Structural design of greenhouse should bear safely to the wind, snow and plant loads and also allow a maximum light to the plant. Berna Kendirli [4] reported that greenhouses in Marmara region had differences concerning their construction techniques and construction and cover materials. There was no standard in the material utilized in construction. This condition prevents the desired success to be obtained from the greenhouses, and increases the affection ratio from the natural conditions. After careful evaluation and performance it was therefore reported that in order to develop the greenhouses facilities in the region, greenhouses must be designed according to standards and regional conditions. Especially wind direction and lightening angles and desires of selected plant must be considered in location selection and directional placement of greenhouse.

Cooling and heating technology

The primary objective of a greenhouse is to produce higher yield outside the cultivation season which is possible by maintaining the optimum temperature at every stage of the crop. An appropriate heating (or cooling) system can be coupled with the greenhouse for this purpose. There are many cooling and heating technologies used for the thermal control of agricultural greenhouses around the world depending upon the climatic conditions of the area. In the cooling technologies, natural and forced ventilation, shading screens &nets, evaporative cooling and earth to air heat exchangers systems (EAHES) are being used. Shen and yu [15] reported that the best cooling method for greenhouses in tropical region is ventilation, fans and with covering materials near infrared reflection. In the heating technologies, water storage, rock bed storage, phase change material (PCM) storage, thermal curtains and EAHES are currently being used.

Studies [17] show that the average greenhouse room air temperature is maintained 7-9^{o}C above ambient during winter nights and 6-7^{o}C below ambient in summer days besides decreasing the daily temperature fluctuations inside the greenhouse. Many researchers [17-18] have successfully demonstrated that the EAHES is the most successfully used composite system for agricultural greenhouses. However, the limitation of using the EAHES is the cost of digging the soil and laying the pipes up to 3–4 m depth. Horizontal layout of the pipe network at this depth is not easy. Moreover, for short term use, the temperature of the soil around the pipe mass gradually increases due to dissipation of heat from the outside pipe surface, thereby decreasing the efficiency of the system. Problem of modeling and control of greenhouse inside climate defined by two variables: the temperature and hygrometry was conducted by researcher [16] with experimental greenhouse located at the campus of University of Toulon (France). Experimental results show that the designed aquifer coupled cavity flow heat exchanger system (ACCFHES) is capable of maintaining the greenhouse room air temperature 7-9^{o}C above ambient in winter months and 6-7^{o}C below ambient in summer months.

Cover material

Radiation is transmitted to the greenhouse through the greenhouse cover (cover material). The greenhouse cover material is a transparent covering for the greenhouse which allows short wave solar radiation to enter and is partially opaque to the long wave radiation leading to a greenhouse effect. The choice of cover material depends on environmental condition and season. The radiation fractions absorbed by the greenhouse cover, plants, soil and water vapour in the greenhouse; and the fraction of radiation lost outside the greenhouse are functions of the radiative properties of the covering material, the soil surface and the plant leaf; and the extinction coefficient of air in the greenhouse. The relations are general and can be used for a greenhouse of any shape and size and at any location under any climatic conditions [9]. Sethi et al. [21] stated that in cold climatic regions around the world, the use of glass, polycarbonate and polyethylene sheet as greenhouse cover materials are the preferred choice because most of the time during the year, greenhouse is kept fully closed for generating maximum greenhouse effect. Sethi and Arora [13] reported that in hot climatic zones, during extreme summer months of May, June and July (off-season for crop production), greenhouses can be used as a crop dryer. It is known that inside a fully closed single polyethylene (PE) cover greenhouse (east-west orientation), air temperature rises about 12-16^{o}C above the ambient air temperature (38-42^{o}C) during the extreme summer months. Bilal et al. [24] studied the effects of different covering films like ultraviolet stabilized, infrared absorbed, single layered and double-layered polyethylene films on growth and productivity of aubergine. The final yield of plants grown in double layer polythene cover were higher among others and whereas light transmission was highest in single layer polythene, intermediate in ultraviolet stabilized and infrared absorbed and the lowest in double layered polyhouses. The plants in double layered greenhouses grew faster (more leaves and flowers) than others.

Orientation and shape

The design of greenhouse should be based upon sound scientific principles which facilitates controlled environment for the plant growth. Controlled environment plant production systems are used widely throughout the world to produce plant materials and products at a time or place, or of a quality that cannot be obtained outdoors. Orientation of the greenhouse is a compromise for wind direction, latitude of location and type of temperature control. Single greenhouses with latitude above 40°N should have ridge running east to west to allow low angle light to enter from side rather than ends. Below 40°N the ridge of single greenhouses should be oriented from north to south, since the angle of sun is much higher. This orientation permits the movement of shadow of the gutter across the green house. The location and orientation of the greenhouse should avoid falling of shadow on the adjacent greenhouses. To avoid the shading effect from one green house to another greenhouse these should be oriented east to West. However, the wind direction and latitude are also to be considered. In this section, research on greenhouse orientation and shape as applicable to cold and composite climates has been reviewed and presented in details.

Sethi [2] evaluated the performance of different shapes of greenhouse for optimal microclimate under Indian climatic conditions. Results indicated that, the variation in greenhouse shape (from uneven to Quonset) can cause up to 3.5-5.5^{o}C drop in the inside air temperature during different hours of the day at 31^{o}N latitude. The pattern and amount of solar radiation availability at different latitudes is different for the same greenhouse shape. Singh and Tiwari [7] studied the works of researchers on greenhouse for cultivation and greenhouse technology and felt a need to define the best greenhouse shape for individual Indian climatic zones along with additional energy requirements to maintain plant temperature using steady state analysis. For energy conservation in the greenhouse system the standard peak uneven span shape of the greenhouse is the optimum shape for the composite climate. Papadakis et al. [12] investigated experimentally using a scale model to determine the solar transmissivity of a single-span greenhouse under Greece climatic conditions. Results show that at latitude 37^{o}C 58'N during winter, the E-W orientation is preferable to the N-S one. The side walls and especially the east and West ones for the E-W orientation, reduce considerably the greenhouse transmissivity at areas close to the walls for long periods of the day when the angle of incidence of solar rays to theses walls is large. Snezana [27] presents an approach to determining the optimum orientation of a greenhouse for year round applications for different climatic conditions in Serbia for uneven span single shape of greenhouse in east-west and north-south orientation. Results shows that east-west orientation of uneven-span solar greenhouse is the best suited during each months for all analyzed latitudes.

Conclusion

From this review, it is concluded that the shape and orientation of a greenhouse plays a significant role in the design of a greenhouse. Based on the critical review of the works of various researchers, results pointed out that:

- The pattern and amount of solar radiation availability at different latitudes is different for the same greenhouse shape.
- East-west orientation is best suited for year round greenhouse applications at all latitudes as this orientation receives greater

radiation in winter but less in summer except near the equator. This effect is more significant at higher latitudes.

- Air temperature remains the highest inside uneven span shape and the lowest in a Quonset shape as compared to other shapes during different months of the year.
- The variation in greenhouse air temperature from uneven-span shape to Quonset shape is 4.6^{o}C (maximum) and 3.5^{o}C (daily average) at 31^{o}N latitude.

Careful selection of shape and orientation with respect to the region and evaluation of greenhouse should maintain an optimum environment for healthy plant growth and maximum yield.

The future of greenhouse food production

As the world population continues to increase, and more agricultural land is lost to urban development, intensive food production in greenhouses may play a more important role in food production. Furthermore, improving economic conditions in developing countries and an increasing preoccupation with health and nutrition will increase demand for high-quality food products. Through controlled climate greenhouses can meet this consumer demand.

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