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Analysis of Climatic Factors for the Selection of Greenhouse Glazing Materials in Ilorin, Nigeria

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Abstract

The effect of climate change in recent times has necessitated the need for a controlled environment for the cultivation of many crops which were hitherto cultivated under natural tropical condition. An appropriate method of accomplishing this is through the use of greenhouses which modify the environment to produce a micro-climate suitable for optimum plant growth. The successful use of greenhouses depends on the choice of appropriate glazing material. Tomatoes are precious crop demanded all year round but the production of which is being reduced by the effect of climate change. Desirous to increase the level of production, the study attempts to identify appropriate glazing material for greenhouse for the production of tomatoes in Ilorin, Nigeria. Climatological data were collected from the Ilorin International Airport and analyzed in order to identify appropriate covering materials for the development of greenhouse structures in Ilorin. Double layer polyethylene and white corrugated polyvinylchloride were the two glazing materials that have the lowest inner surface temperatures and also satisfy the condition of heat load. To derive the maximum benefits of greenhouses, in addition to using these materials, Proper ventilation and shading of the greenhouses are recommended.

***Keywords:** Greenhouse, inner surface temperature, radiant heat load, glazing materials, tomato production.*

1.1 Introduction

A greenhouse which is also referred to as a botanical garden , conservatory or an orangery, is a structure that is designed and equipped with accessories that enables it to provide a micro - climate irrespective of the prevailing environmental conditions (Basu *et al*, 2006). This attribute enables crops to be cultivated outside their normal production seasons and also makes it possible to cultivate some crops in where they would naturally not survive. Greenhouses have been in use in Europe for thousands of years where they were first used to grow plants indoors throughout inclement weather. The ancient Romans ensured the survival of vegetables and grapes by protecting them from stormy and colder weather in early versions of the greenhouse. The early greenhouses were mainly used for the production of specialty crops for the emperors (Butti and Perlin, 1981).

Modern greenhouses originated in Italy in the thirteenth century to accommodate the exotic plants brought back to Europe in early plant hunting expeditions and later became common in universities with the study of botany. Different types of greenhouses are available ranging from institutional mainly for research to commercial ones used for large scale production of specialty crops. Greenhouses especially the commercial types are widely used in temperate countries where the objective is to maintain a warm micro-climate.

The natural climate of tropical countries including Nigeria, favour the cultivation of many crops such that the modification of the plant environment was hardly necessary hence only a few institutional greenhouses may be identified in Nigeria at present. Global warming and climate change are gradually disrupting the natural climate of many tropical countries and there is increasing need to regulate the environment for the cultivation of some crops. Import restrictions and quarantine regulations are also increasing the need to introduce certain crops to areas within the where they were not originally cultivated. Many societies may have no alternative other than to introduce commercial greenhouses.

Greenhouses are capital intensive structures which should be used in situations where the investments can be recovered in a record time. The success recorded with greenhouse crop production depends to a large extent on the glazing material since that is what determines the type of micro-climate achievable within the greenhouse. There are a variety of glazing materials as presented in from which a choice could be made. In practice the choice of a glazing material is made taking into account the climate of the environment where it is expected to be used. Dayan *et al* (1986) undertook a comparative study of the potentials of greenhouses constructed with glass (G); Polyethylene (P.E.), Fiberglass (FG.) and Polycarbonate (P.C.) for tomatoes production in the Besor Region of Israel and found that greenhouses with glass and polyethylene as glazing materials performed better because of the low indoor night temperatures with glass and low radiation level in polyethylene greenhouses.

Tomato (*Lycopersicon esculentum* Mill.) is one of the most commonly grown and widely used vegetables for culinary purposes all over the world (Madhavi and Salunkhe, 1998) . The environmental requirement for its cultivation varies from one region of the world to another and also with the variety. It is one of the major greenhouse vegetables. Greenhouse tomatoes offer a range of advantages, such as higher quality, more yield, risk reduction in cultivation and in some areas out of season production (Mike and Martin, 2009). Tomato is a delicate vegetable that is very susceptible to extreme temperature variations. Moore and Thomas (1952), observed that high light intensity accompanied by high temperature was harmful to tomato. Tomatoes can be grown on a wide variety of soils ranging from light-textured sandy or sandy loam to heavier clay soils. Like other vegetable crops, tomato also grows better and yields more when grown in a rich sandy loam or loamy soil. The soil should be rich in nutrients and organic matter. The ideal pH should be near neutral but never below 6.0 or above 7.0. Tomatoes thrive well when the weather is clear and rather dry, and the temperatures are uniformly moderate in the range of 18 – 30 °C, but grow best with average monthly temperatures of 21 – 24 °C (Mike and Martin, 2009). The extreme temperature for tomato production was found to be around 12 – 35 °C (Anonymous, 2011.) Despite the wide cultivation, the demand for tomatoes often falls short of the supply. Kabura *et al*, (2009), reported that the production of tomato in relation to demand is generally low in Nigeria and this could be particularly attributed to the prevailing high temperatures in most parts of Nigeria. Even where the cool temperature is obtained (mostly in the Northern parts of the country), such temperature prevails only during the harmattan period from November to February. Outside the short cool period, fresh tomato is very scarce and expensive in the whole country.

There is the need to increase the availability of fresh tomato to meet up with the high demand for this commodity, particularly during the hot season in Northern Nigeria. Tomatoes are important sources of lycopene and vitamin C known for its therapeutic and antioxidant properties and are valued for their colour and flavor (Deshpande *et al,* 1995). The fruit is consumed fresh and utilized in the manufacture of a range of processed products such as puree, paste, powder, ketchup, sauce, soup, canned whole fruits (Mike and Martin, 2009). The fresh fruits are known to be effective as digestive aids and in the treatment of kidney and liver problems. The protective effects of tomatoes against cancers of the digestive tract have been reported from different parts of the world. Corditz *et al* (1985) reported a significant 50% reduction in mortality from cancers of all sites among elderly Americans with high tomato intake.

The Lake Chad region is the main supply of tomatoes especially at the off - season period and this has been attributed to the favourable microclimate (relatively high humidity and cool temperature in the area) prevailing in that region. The provision of similar micro climates in other parts of the country could increase the volume of production and reduce scarcity. A greenhouse is appropriate to provide such conditions. An important element of greenhouse efficiency is the type of glazing material used as this determines the temperature maintained in the structure and the heat stress level to which the plants are exposed.

Ilorin, the capital of Kwara state is part of the middle belt and shares the characteristics of the extreme north and south of Nigeria. Tomato is popularly cultivated in the state but extremely scarce at off season period aggravated by high temperatures. A micro climate that allows all year round cultivation of the crop will no doubt increase the volume available and hence the idea of providing commercial greenhouses for tomatoes production in Ilorin. The main thrust of this study was to identify appropriate glazing materials for greenhouses that may be used in Ilorin environment for the production of tomato.

2. Materials and Method

2.1 Study Area.

The area for which the glazing materials are to be used is Ilorin, the capital city of Kwara State and its environs. Ilorin is located between latitudes 11°2' and 4°51'N and longitudes 2°45' and 6°40'E at an altitude of about 375m. The natural climate is characterized by both the wet and dry seasons with the rainy season beginning towards the end of April and lasting till October while the dry season begins in November and ends in March. Days are very hot during the dry season with November to January temperatures rising up to 34°C, while from

February to April, the temperature further increases to between 34.6° C and 37°C. The total annual rainfall in Ilorin is about 1318mm. The relative humidity in the wet season is between 75% and 80% while in the dry season, it is about 65% (Tinuoye, 1990). The sunshine period is between 6.5 - 7.7 hours daily from November to May (Olaniran, 1983). Kwara state is one of the food basket regions of Nigeria where crops such as maize, yam, rice and assorted vegetables are cultivated. Tomato is widely cultivated in the state.

2.2 Data Collection

The temperature and sunshine data for a period of eight years (2000 to 2007) were collected from the Nigerian Meteorological Agency (NIMET), Ilorin International Airport, Ilorin, Kwara state, Nigeria and the summary is presented in Table 2 and 3.

2.3 Analysis

The two parameters that were relevant to the choice of glazing materials were the inner roof surface temperature and the radiant heat load for each of the various glazing materials. These parameters were calculated using the following equations.

2.3.1 Inner Roof Surface Temperature

The inner temperature of a roof can be calculated from the following equation presented by Lindley and Whitaker (1996)

$$t_e = t_o + \left(\frac{\alpha I}{f_c}\right) \qquad (1)$$

where,

t_e = Inner surface temperature.
t_o = Ambient air temperature
α = Solar absorptivity of the covering material
I = Combined incident radiation
f_c = convective film coefficient

The outside roof surface film convective heat transfer coefficient (f_c) is often assumed to be 22.7W/m^{2o}C (Lindley & Whitaker, 1996) while the maximum monthly daily total of diffuse radiation for Ilorin as reported by Iziomon and Aro (1995) was 450 W/m^2.

2.3.2 Radiant Heat Load (RHL)

The radiant heat load depends on the mean radiant temperature. The mean radiant temperature, T_m, can be used to calculate the radiant heat load (RHL) as follows:

$$RHL = \sigma T_m^4 \qquad \text{(Lindley \& Whitaker, 1996)} \qquad (2)$$

where,

σ = Stephan-Boltzmann constant which equals 5.67×10^{-8} W/m^{2}K^4
T_m = mean radiant temperature.

3. Results and Discussion

The results of the calculations are presented in Tables 4 and 5.

3.1 The Inner Roof Surface Temperature

The inner surface temperature will be a guide in selecting a covering material such that the temperature on the inner surface of the roof will be close to that required by the crop being produced. The inside surface temperature of different covering materials at Ilorin, Kwara State, Nigeria is as shown in Table 4.
The result of the radiant heat load which is an indication of the level of stress the plants inside the greenhouse will be subjected to, is presented in Table 5

The inner surface temperatures for white corrugated polyvinylchloride (PVC) and double layer polyethylene recommended were 44.66°C and 46.83°C respectively. As reported by Kabura and Abubakar (2009), the heat resistant varieties of tomato could withstand temperatures between 25 and 41°c while the optimum temperature for the common varieties is between 18 - 30°c (Madhavi and Salunkhe, 1998). As a result, it is necessar consider covering materials with the lowest inside roof temperatures for optimum regulation. Double la polyethylene and white corrugated polyvinylchloride (PVC) are recommended because they have the low inner surface temperatures which are closer to the temperature requirement for the production of heat resist varieties of tomatoes

Since the inner surface temperatures for these covering materials are higher than the ambient temperature, i necessary to design for ventilation that will regulate the temperature within the range that will be suitable for growth of the crop. This can be achieved by designing greenhouse structures in this region to maximize b wind and chimney effects or by evaporative cooling.

4. Conclusions and Recommendations

Temperature data were obtained for Ilorin and used in predicting the inner surface temperature and radiant h load for various glazing materials. The double layer polyethylene and white corrugated polyvinylchloride are t two glazing materials that have the lowest inner surface temperatures and also satisfy the condition of heat lo Double layer polyethylene was found to be more preferable considering the advantages of its cheapness, easy install and readily available in large sheets. These materials are therefore recommended as glazing materials f greenhouses meant for tomato production in Ilorin environment.

Also, the major critical factor that needs serious regulation is the temperature because of the difference betwe the inner surface temperatures of the covering materials and the desired temperature. To achieve thi greenhouse structures for crop production in Ilorin must be properly ventilated and shaded to moderate the he stress on the crops.

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Table1. Information on commonly used glazing materials

Material	Composition	Advantages	Disadvantages	Light Transmittance
Glass	Mixture of Silica, an alkali (Soda or Potash), lime, oxides (lead, boron, barium, cerium, manganese) and cullet.	• Excellent transmittance • Superior resistance to heat, ultraviolet radiation and abrasion • Readily available • Transparent.	• Low impact unless tempered • High cost • Heavy	• Single layer :0.90 • Double layer: 0.75
Acrylic	Methyl metharcrylate polymers.	• Excellent transmittance • Superior ultraviolet and weather resistance • Light weight • Easy to fabricate on site • Strong and shatter resistance.	• Easily scratched • High expansion and contraction • Relatively low service temperature • Flammability	Laminated–0.87
Polycarbonates	Long-chain linear polyesters of carbonic acid, dihydric phenol and ultra-violet (UV) stabilizers	• Excellent service temperature • High impact resistance • Low flammability • Excellent dimensional and colour stability.	• Scratches easily • High expansion and contraction	Coated – 0.90 Uncoated - 0.88 Double wall:0.83 Triple & Quad wall: 0.75
Fibreglass Reinforced Polyester	Glass fibre, polyesters, vinyl esters and phenolics	• Low cost • Strong • Easy to fabricate and install	• Susceptible to ultraviolet rays, dust, and pollution degradation • High flammability	0.85
Polyethylene film (PE)	Petroleum products.	• Inexpensive • Easy to install • Readily available in large sheets.	• Short life • Low service temperatures	Single layer : 0.8 – 0.9 Double: 0.6–0.8
Polyvinylchloride Corrugated (PVC)	Polychloride Resin, Red soil, anti-UV agent	• Durable • Good fire rating • High impact strength • Infrared inhibitor	• Lower light transmittance • High expansion	Clear – 0.89 White – 0.52

Source: Giacomelli, 1999

Table 2: Ambient Temperatures °C for Ilorin, Nigeria.

Month	Years								Average
	2000	2001	2002	2003	2004	2005	2006	2007	

January	34.4	34.2	32.3	34.8	34.1	34.1	33.1	33.4	33.8
February	34.7	35.9	36.5	36.6	36	36.7	36.2	36.4	36.1
March	36.9	37.2	36.7	37.1	35.9	36.3	34.4	36.9	36.4
April	34	35.5	34	33.8	34.1	35	35.7	33.9	34.5
May	33	33.2	33.5	33.1	31.7	31.3	31.2	32.2	32.4
June	30.6	31	31.7	30.2	30.1	30.1	30.6	30.7	30.6
July	29.7	29	29.5	29	29.1	28.6	29.4	30	29.3
August	28.6	28.4	28.5	29	29.5	28	27.6	29	28.6
September	30	29.7	29.8	29.7	29.7	29.6	29.7	30.1	29.8
October	30.9	32.7	30.9	31.9	31.1	30.8	31.5	31.4	31.4
November	35	35.5	34.1	34	33.1	34.1	33.6	33.8	34.2
December	34.4	35.5	34	34.3	34.4	34.2	33.8	34.3	34.4

Source: Nigerian Meteorological Agency (NIMET), Ilorin International Airport, Ilorin, Kwara state, Nigeria.

Table 3: Sunshine Duration (hours) for Ilorin, Nigeria.

Month	Years								Average
	2000	2001	2002	2003	2004	2005	2006	2007	
January	8	7.2	6.6	8.1	7.6	7.2	7.1	5.5	7.2
February	8.7	8.9	7.3	7.9	8.9	8.1	8.9	6.9	8.2
March	9.3	9.6	9.4	9.1	8.4	9.2	9.2	6	8.8
April	9.1	9	8.7	9.5	7.1	9.1	8.8	7.8	8.6
May	8.5	8.4	7.1	8.6	6	8.1	6.9	7.3	7.6
June	5.3	7.2	6.2	6.2	5.9	7.1	5.8	6.5	6.3
July	4.3	6.4	5.3	5.3	4.6	6.7	4.5	5.2	5.3
August	5.2	5.2	4.2	4.2	5.1	5.8	3.6	4.2	4.7
September	6.3	6.1	5.1	5.1	6	7.1	4.4	5.5	5.7
October	5.1	6.8	6.1	4.9	3.2	8.3	6.3	7.8	6.1
November	8.4	7.8	7.3	7.2	6.9	8.6	8	7.6	7.7
December	7.4	8.3	6.2	8.1	8.4	7.7	8.5	7.2	7.7

Source: Nigerian Meteorological Agency (NIMET). Ilorin International Airport, Ilorin, Kwara state, Nigeria.

Table 4: Inside Surface Temperature and Radiant Heat Load with Different Glazing Materials at Ilorin.

Covering materials	Solar absorptivity (or light transmittance)	Outside air temperature (°C)	Inside surface temperature (°C).
Glass: Single layer	0.90	34.35	52.19
Double layer	0.75	34.35	49.22
Acrylic (Laminated)	0.87	34.35	51.60
Polycarbonate:			
• Double wall rigid	0.83	34.35	50.80
• Triple and Quad wall rigid	0.75	34.35	49.22
Fibreglass Reinforced Polyester	0.85	34.35	51.20
Polyethylene:			
• Single layer	0.85	34.35	51.20
• Double layer	0.70	34.35	48.23
• Corrugated high density	0.75	34.35	49.22
Polyvinylchloride (PVC):			
• White Corrugated	0.52	34.35	44.66
• Clear Corrugated	0.89	34.35	51.99

Source: Author's Computation, 2009.

Table 5: Radiant Heat Loads (RHL) for Different Covering Materials

Covering material	Mean radiant temperature, K	Radiant heat load(RHL) W/m²
Single layer glass	325.19	634.66
Double layer glass	322.22	611.21
Laminated acrylic	324.60	629.47
Double wall rigid polycarbonate	323.80	623.29
Triple and Quad wall rigid polycarbonate	322.22	611.21
Single layer polyethylene	324.20	626.38
Double layer polyethylene	321.23	603.74
Corrugated high density polyethylene	322.22	611.21
Polyvinylchloride (PVC) Corrugated (white)	317.66	577.34
Polyvinylchloride (PVC) Corrugated (clear)	324.99	632.50
Fibreglass Reinforced Polyester	324.20	626.38

Source: Author's computation, 2009.