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ORIGINAL RESEARCH ARTICLE

EVALUATION OF A LOW-COST GREENHOUSE FOR CONTROLLED ENVIRONMENT CULTIVATION OF SWEET PEPPER

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ABSTRACT

Sustainable agriculture is critical towards paving a way for year-round production and supply of food all year round. Cultivation of fruits and vegetables are vital due to high demand and nutritional values it provides to consumers. The rising global population especially in developing countries require other alternatives for sustainable crop production. Cultivation in controlled environments using functional and durable greenhouse structures presents an option. A low-cost greenhouse was designed and constructed in Ibadan, Nigeria using locally available materials was evaluated. Afrormosia wood was used in constructing the frame while polyethylene of 2.5 mm thickness was used as sheathing material for the walls. The floor which covered an area of 24 m^2 was made of porous concrete of batching mixture 1:4 (cement to gravel) while the wall was 4 m high. Ventilation was passive with a vent area equal to 25% of total surface area; made up of 20% at the wall area and 5% as the roof vent. The roof was pitched at a 18° slope to allow easy drainage of rain water. Sweet pepper (Capsicum annuum, Cabernet) seeds procured Burpee Seeds USA were cultivated with the aid of planting pots within the greenhouse in comparison with those planted in the open field for a duration of eight weeks. Evaluation was based on crop growth and yield parameters correlated with solar radiation, temperature and relative humidity in the greenhouse and ambient environments, respectively using randomized complete block design. Data were subjected to descriptive and correlation analysis. Peak temperature and RH were 31.1°C and 91.1% respectively within the greenhouse in comparison with 29.7°C and 89.7% respectively outside. Peak solar radiation was 413.4 W/m^2 in the greenhouse compared to 690.3 W/m^2 in the ambient. Growth parameters showed that the crops in the greenhouse performed optimally when compared with plants in the open field with a yield of 18.1 t/ha in the greenhouse compared with no-yield recorded in the open field. Utilization of greenhouses in crop cultivation can help to mitigate the problem of food shortage.

1.0 Introduction

Climate change as well as continuous increase in population has necessitated the need for highly productive agriculture (Lutz, 2017). Climate change is one of the most serious environmental and human threats undermining the achievement of agricultural production in almost every part of the world. It is a real threat to lives and livelihoods as well as to the environment (Stephenson et al., 2010). If food security will be attained, technologies that minimize external threats to crops and increase crop production are needed. One major way of providing efficient agriculture while preserving the quality of the environment is through greenhouse cultivation. Greenhouse allows for the manipulation of essential variables such as temperature and relative humidity to achieve optimal crop production.

Controlled environment agriculture (CEA) is the alteration of the environmental conditions to achieve a desired conducive environment for crop and animal production. Cultivation of crops in greenhouses can be independent of environmental conditions, thereby boosting the possibilities of multiple harvest as compared to the seasonal open field agriculture. Controlled environment agriculture is a technology-based approach toward food production Albright (1990) with the aim of providing a protected environment for crop growth while maintaining optimal growing conditions throughout all developmental stages. Forms of controlled environment agriculture include hydroponics, aeroponics, aquaculture and aquaponics. The benefits of controlled environment are numerous and far reaching and include, high volume of local food production in urban and exurban environments on a year-round basis, optimal growth conditions that eliminate the need for chemical fertilizers and harmful pesticides, controlled nature of food production significantly reduces water use and protects water quality.

Generally, greenhouses are defined as structures used to control environmental conditions for different crop cultivations (Mijinyawa and Osiade, 2011). Although, climatic conditions affect crop production in the open field, the effects are limited in a controlled environment facility because greenhouses are built to provide a conducive environment irrespective of climatic conditions (Jones and Harrison, 2004; Gorjian et al., 2011). It has also been reported that the application of greenhouse technology is economical on the long run in planting different crops, both in small and large-scale production (Cook and Calvin, 2005).

Interestingly, within a greenhouse, structural, mechanical, nutritional, and micro-climatic conditions are optimized to achieve the desirable crop growth (Connellan, 2002, Shamshiri et al., 2018). Geometry, dimensions, and roof characteristics; reduction of solar intensity using shades and vents; forced air circulation and evaporative cooling are manipulated to achieve optimal air temperature, relative humidity and illumination (Ponjican et al., 2011). These factors are vital in achieving productive and sustainable crop cultivation in a greenhouse. Ali et al. (2012) reported that the production of horticultural crop provides more job opportunities per hectare of production in comparison to cereal crop. A good perspective of increased employment opportunities can be observed from the gradual shift of cereal production to high value horticultural crops such as tomatoes in some parts of the world (Rao et al., 2003, Ibeawuchi et al., 2015).

Babatola (2004) highlighted some challenges facing the agricultural sector such as poor extension services, land tenure, limited planting materials, low technology application, and limited postharvest facility. Crop cultivation in greenhouses is a viable option towards increasing crop production. Modern and conventional greenhouses are expensive to set up. The development of greenhouses from locally available materials will be a welcome development. This paper provides details of the design, construction, and evaluation of a low-cost greenhouse for cultivation of sweet pepper.

2. Methodology

2.1 Design

The design considerations were based on possible external and internal loads on the structure, materials of construction, durability, rigidity, and microclimatic conditions. The construction site is a swampy reclaimed soil with laterite. The site is water-logged in the rainy season with high water-table. Moreover, the unproductive nature of the area made the location a good ground for greenhouse evaluation. Adequate natural ventilation was provided with a vent of about 25% of the wall area.

Afrormosia lumber (known locally as Ayin wood) material was used in the construction of the greenhouse frame due to its durability, hardness, workability, and ready availability. The following parameters were utilized in the design of the greenhouse according to Mijinyawa (2012), based on green grade moisture content of 40%; permissible bending stress parallel to grain (11.2 N/mm^2), permissible shear stress (1.4 N/mm^2), compression parallel to grain (9.0 N/mm^2), modulus of elasticity, E (13,200 N/mm^2) and density (650 kg/m^3). All structural components which made up the frame (purlins, rafters, beams, and columns) were designed using standard procedures. Wind load was calculated from the expression $q = 0.0127 \times V^2 \times k$ (where q = velocity pressure in N/m^2, V = wind velocity in m/s and k is a constant relating to the height of the building in m, FAO, 2011). Some of the other design parameters adopted are given in Table 1.

Table 1: Design parameter and values of the greenhouse structure

S/N	Parameters	Values
1	Greenhouse dead-load, w	15.9 N/m
2	Wind load, q	4.24 N/m^2
3	Polythene covering density (low range)	0.925 kg/cm^3
4	Polythene thickness covering	2 mm
5	Slope angle of roof	18°
6	Bending and allowable stress of purlin	0.56 N/mm^2; 11.20 N/mm^2
7	Maximum bending moments for beam	43.1 Nm;
8	Greenhouse floor area	24 m^2
9	Total roof vent area	2.16 m^2
10	Length of greenhouse	6 m

2.2 Construction

The frame of the greenhouse was constructed using 100 by 100 mm wooden columns, installed 400mm into the foundation slab. The floor was constructed using concrete grade C20 (mixing ratio 1:3:5) as recommended by FAO, (2011) and a black coloured plastic film was incorporated as the damp-proof course (DPC) level as in Figure 1. The floor had a gentle slope of about 5° to allow efficient water drainage. A transparent plastic sheet (polyethylene) of 2 mm thickness was used as the covering material (Figure 2). It was selected because it is cheap, readily available, has good light transmittance and easy to use. This was achieved through the provision of top and side vents across the length of the greenhouse. The side vents were 1 by 6m while the tope vents were 0.2 by 6m in dimension, to allow cool air to flow through the side vents driving warm air out through the roof vents.

Figure 1: The Greenhouse floor at the DPC level

Figure 2: Greenhouse Covering the greenhouse

2.3 Evaluation

Temperature and relative humidity profiles were monitored in the greenhouse after which an evaluation was carried out by cultivating sweet pepper (Capsicum annuum, Cabernet). The seeds were obtained from Burpee Seed Company, USA and raised in the nursery for four weeks. The seedlings were thereafter transplanted from the nursery to the greenhouse on the 10th of September 2016 into 33 plastic pots with a volume of 10 liters each (Figure 3). Sandy-loam soil was obtained, and thoroughly mixed and foreign materials removed. The mixed soil was then filled into the plastic pots and watered to set before transplanting. Nitrogen-Phosphorus-Potassium (NPK) fertilizer (15:15:15) was applied on the soil; the first application was performed two weeks after transplanting while the second application was performed three weeks later. The transplanted seedlings were adequately watered and monitored for any development. The control experiment was set up in an open field beside the greenhouse and the pepper seedlings were transplanted and monitored. Crop performance (plant height, number of leaves, leaf area index and yield) were measured and recorded.

Plant height was measured from the base of the soil to the collar of the uppermost leaf using a ruler. Five plants per row were sampled for crop performance parameters on a weekly basis. These were also measured for the control experiment. The leaf area was traced out on graph paper to measure area. From this measurement, this surface area and leaf area index were estimated by the formula:

$$\text{Leaf Area index (LAI)} = \frac{LA}{SA} \quad (1)$$

where: LA is the Leaf Area and SA is the Soil surface area covered by the plant.

Temperature and relative humidity data loggers (Lascar EL-USB 2 model, Lascar Electronics, USA) were placed inside and outside the greenhouse to record both ambient and greenhouse conditions. The data loggers were set to read at every one-hour interval. A light meter (Solar Power Meter SM-206) was also used to record the light intensity entering the greenhouse daily while a digital weighing scale (Accuris Instruments W3300 with a capacity of 10 kg, 1 decimal place) was used to measure the weights of the harvested pepper. Data collected were subjected to correlation and descriptive statistics.

3. Results and Discussion

3.1 Temperature and Relative Humidity Trends

Ambient and greenhouse temperature trends during the two-month evaluation period are shown in Figure 3. The greenhouse had a peak temperature of 31.1°C while that of the ambient temperature was 29.7°C. Expectedly, greenhouse temperatures were higher than that of the ambient as radiant energy from the sun heats up the structure and part of the heat is trapped within. The temperature ranged between 26.5 to 31.1°C in the greenhouse throughout the entire growing period. This is considered suitable for sweet pepper production, which is known to perform well within maximum air temperature up to 35°C (Kittas et al., 2005). Similarly, relative humidity (RH) data showed that the greenhouse had a peak RH of 91.1% while that of the ambient RH was 80.4% (Figure 4). Moreover, RH within the greenhouse was consistently higher than that of the ambient which can be attributed to the consistent application of water within the structure to meet the crop water requirements of the plants (Omid and Shafei, 2005).

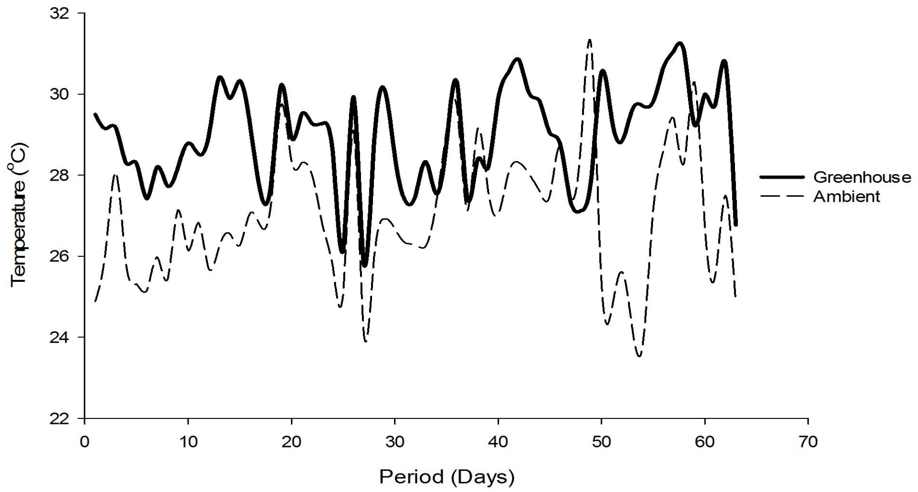

Figure 3: Mean daily temperature trends in the greenhouse and ambient environment

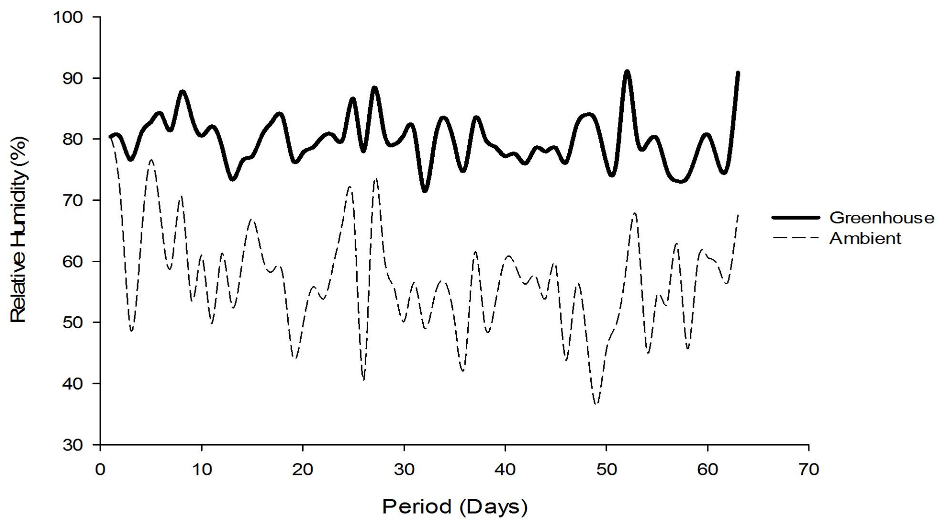

Figure 4: Daily relative humidity trends in the greenhouse and ambient environment

3.2 Solar Radiation

The peak solar radiation within the greenhouse was 413.4 W/m^2 while that of the ambient was 690.3 W/m^2. Ambient solar radiation was consistently higher than that of the greenhouse is due to the direct radiation from the sun, unlike the greenhouse where part of the solar radiation is diffused as it passes through the covering material (polythene). The relatively low-cost covering material was however suitable as it allowed sufficient solar radiation needed for photosynthesis into the greenhouse (Figure 5).

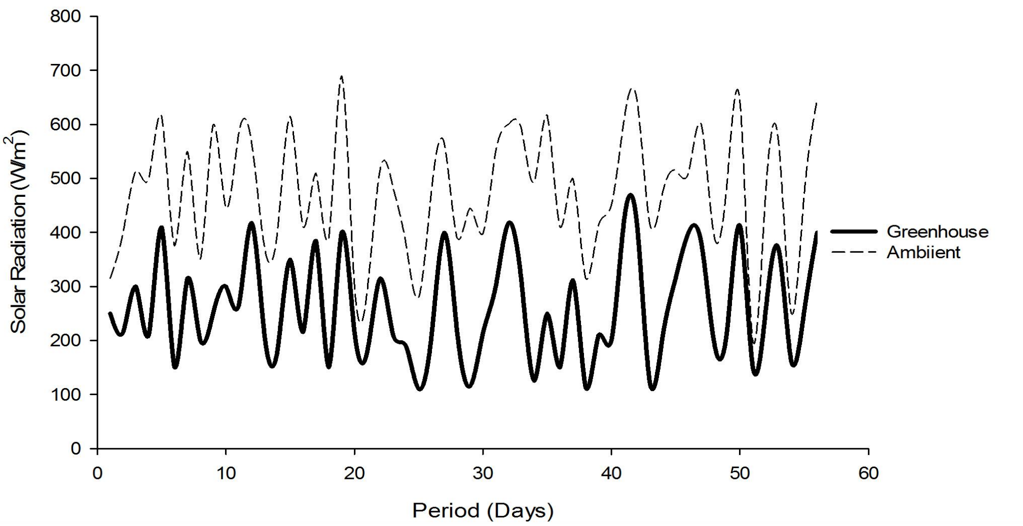

Figure 5: Daily solar radiation trends in the greenhouse and ambient environment

3.3 Crop Performance

Sweet pepper planted in the greenhouse performed better throughout the period of evaluation compared to the open field crops. Comparison between mean plant height, number of leaves and leaf area of crops in greenhouse and open field at the end of the evaluation were 200.0 ± 17.6 and 89.5 ± 18.3 mm, 30.7 ± 7.87 and 10.8 ± 2.58 and 28.0 ± 8.67 and 7.4 ± 2.12 mm^2 respectively (Figures 6-8). Similar results were reported by Priya et al. (2002) in sweet pepper. Moreover, within the greenhouse, mean stem diameter, leaf girth, root depth and shoot height were 4.21 ± 0.57 mm, 61.7 ± 18.29 mm, 126.1 ± 37.14 mm and 182.0 ± 48.32 mm respectively (Figure 9). A total mass of 1,874.5g of sweet pepper fruit was harvested from the greenhouse, equivalent to 18.1 t/ha when the soil surface area in the greenhouse is considered. Typical yields of sweet pepper ranges between 10 to 30 t/ha (Stoffella et al.,1995; Alsadon et al., 2013; Dagnoko et al., 2013). In contrast, the open field crops yielded no fruits in addition to the fact that the crops were stunted (Figure 10). These results agree with the findings of Papadopoulos and Ormrod (1991).

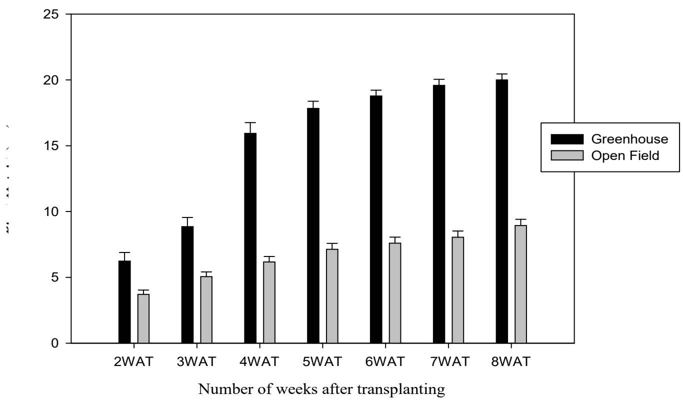

Figure 6: Mean plant height under green house and open field cultivation

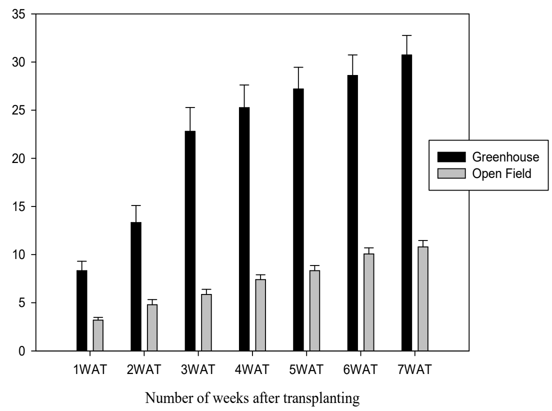

Figure 7: Mean leaf count under green house and open field cultivation

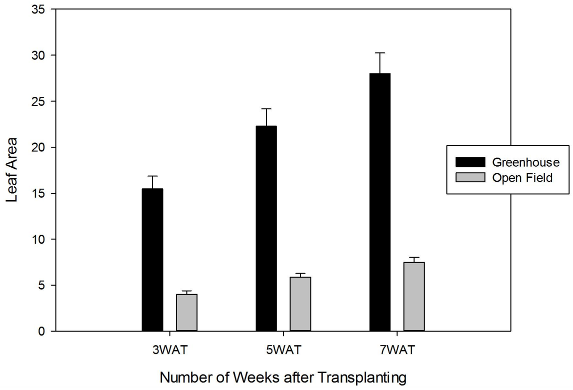

Figure 8: Mean leaf area under green house and open field cultivation

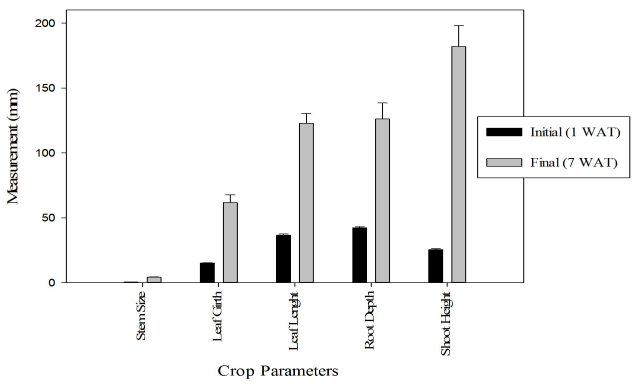

Figure 9: Crop Parameters within the Greenhouse

Figure 10: Greenhouse and open field sweet pepper 7 weeks after transplanting

4. Conclusion

This study evaluated the performance of sweet pepper grown in a low-cost greenhouse in comparison with field growth conditions in an agriculturally unproductive soil. The greenhouse crops showed increased plant height, number of leaves and leaf area index, which translated into increased yield. Observations confirmed that in the greenhouse, there is reliability of yield which shows the possibility of year-round production in an unproductive environment. The high performance observed in crops grown in the greenhouse is attributed to improved leaf physiology (i.e. increased number of stomata) and adequate photosynthesis. Moreover, the micro-climate within the greenhouse was adequate for the crops to survive. However, due to the nature of the soil in the open field experimented, crop performance was extremely poor. This study recommends further work to evaluate performance using other crops across different seasons of the year with different water application regimes. Performance under ventilated conditions should also be considered. Advocacy to farmers living close to poor agricultural or degraded soils on the potentials of low-cost greenhouses should also be intensified.

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