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# GREENHOUSE (GH) TRENDS IN AGRICULTURE: A REVIEW

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**Abstract:** Greenhouse (GH) technology has been employed in the production of selected crops under a controlled environment for maximum yield. Most often, flowers, medicinal plants and short-duration arable crops are most favoured for cultivation in greenhouses for research and commercial production purposes. Greenhouse is beginning to gain acceptance and usage in crop production in Nigeria in particular. This paper focused on the: origin of greenhouse, type of GH, general research trend in GH development/technology, adaptable irrigation type for GH farming, design criteria for GH, trends in smart GH/farming and GH development and utilization across the globe to produce food crops sufficiently and for future food scarcity. Site selection is a key factor for profitable and sustainable greenhouse production where factors like climate, topography, irrigation water, soil characteristics, flooded areas, air pollution, expansion, labour availability, communications network and orientation affect the utilization of greenhouses for research and production purposes. The types, styles, materials selection and uses, sizes of greenhouses, should be considered in conjunction with factors that determine the siting of greenhouses. Existing localized irrigation methods commonly utilized for crop cultivation include surface (Sprinkler), subsurface (Drip, emitter). The selection of types of GH and irrigation method depends on influencing factors.

**Keywords:** greenhouse, agriculture, IoT, artificial intelligence, smart agriculture

## INTRODUCTION

Greenhouse (GH) is a farm structure that could be made of glass (glasshouse), plastic material of various types (greenhouse), and or of screen materials (screen house) (Bartok, 2000). Greenhouse (also called glasshouse, hothouse, screen house, shade house and crop top structure) is a system for modification and management of environmental factors that allows plants to be grown in suitable climates that may not well be suited for their growth and development. In brief, a greenhouse farming optimizes growing conditions and protects the crops from extreme weather events, protect crops from pests and diseases, enables effective crop managements. In the 17$^{th}$ – mid 19$^{th}$ century, greenhouses are commonly made of brick or timber with normal proportion of window space and some means of heating, Samapika, *et al.,* 2020, Tiwari, 2003. No matter the type or material used in the construction of these types of structures, they are all generally referred to as greenhouses (FAO, 2011; Bartok, 2000; Castilla and Baeza, 2013). The purpose of employing any type of greenhouse in agriculture is to prevent undue interference of the environment and prevent diseases and pest from influencing or altering the physiological makeup of the crop(s) intended to be planted for research or commercial production. Greenhouses are important in agriculture, horticulture and botanical science. The modern greenhouse is usually a glass or plastic enclosed frame structure, used for the production of fruits, vegetables, flowers and any other plants that require controlled environment for it survival. Components such as cover materials, climate-control systems, and irrigation and fertilization equipment are regularly evaluated by growers, designers and researchers, to improve their efficiency, lower inputs, and reduce undesired environmental effects, Samapika, *et al.,* 2020, Rajender, *et al.,* 2017; Tiwari, 2003. There are different type of greenhouses, however, polyethylene or polyvinyl, fiberglass, plastic films, transparent and translucent are commonly used as cover materials while the frame structure could be made of aluminum, galvanized steel or such woods as redwood, cedar or cypress. A greenhouse can become too hot or cold, some type of ventilating system is usually needed to provide optimum environment for growth and production of given plant. The plants cultivated in greenhouses fall into several broad categories based on their temperature requirements during nighttime hours. In a cool greenhouse, the nighttime temperature fall to about 7 – 10 ºC. Among the plants that thrive in cool greenhouse are azaleas, cinerarias, cyclamens, carnations, fuchsias, geraniums, sweet peas, snapdragons and various types of bulbous plants like daffodils, irises, tulips, hyacinths and narcissi. A warm greenhouse has nighttime temperatures of 10 – 13ºC. Begonias, gloxinias, African violets, orchids, roses and many kinds of ferns, cacti and other succulents are adaptable to such temperatures. In the tropics, greenhouse has nighttime temperature of 16 – 21 ºC, variety of palms and orchids can be grown, Rajender, *et al.* (2017)

Greenhouse farming is a broad term that involves various types of sheltered structures. Important elements that are associated with this type of farming include shape of the structure, lifespan, cover material, size of the farm and level of farm management technology. Each greenhouse structure is inclusive of aspects that react differently then and to other management aspects. These include: the amount of sunlight, the amount of natural ventilation, the size of the farm, heating requirements, condensation run-off, efficiency of materials and costs, Samapika, *et al.,* 2020, Tiwari, 2003.

Montero *et al.* (2013) and Connellan (2002) reported that greenhouses could be categorized as low cost, medium cost or high-cost technology depending on the design and materials used. To design and construct an efficient and effective greenhouse for best management practice (BMP), the location, topography, soil characteristics, water quantity and quality, labour availability, etc. must be considered (Kumar *et al.*, 2006; Cox *et al.,* 2010; Brian *et al.,* 2015; Sabin *et al.,* 2020).

In Nigeria, the use of greenhouses is still obscured and probably restricted to farms in research institutions like IITA, Obasanjo farms, etc. or in the Universities/ research institutions. Crops planted for study are protected from extreme weather conditions that affect their growth while crops' environments are better managed to reduce the harmful effect of pest and diseases, therefore, these plants can be grown and made available throughout the year. Greenhouses are classified as either domestics, plastics or commercials, in Nigeria (agricdemy, 2020).

The use of irrigation technology in farming in Nigeria, especially in the southern region is very limited compared to the northern region. Irrigation technology still remains the available option to supplement natural rain-fed agriculture, particularly in a greenhouse. However, the choice of a particular irrigation system is affected by factors like climate, topography, soil characteristics, water quality and quantity (Arora, 2012; Waller and Yitayew, 2016).

The effects of greenhouse gas emission, its effects on the environment as well as the drying mechanism of greenhouse are not considered in this review. This review is focused on the greenhouse for farming purposes; types of greenhouses and their evolution over the years, general research trends in GH technology and current trends in the utilization of greenhouse for food security and sustainability.

## MATERIALS AND METHODS / GREENHOUSE

Published articles (Literature) ranging between year 1989 – 2020, over three decades, were downloaded and used for the review. The downloaded literature were sorted out and categorised into those that reported on the origin of greenhouse (GH); type of existing GH; general research trends in GH development; adaptable irrigation type for GH farming; design criteria for GH; trends in smart GH/farming; special GH design methods and innovations in GH technology.

## RESULTS AND DISCUSSION

### — Types of greenhouses

Classification of greenhouses is done based on different parameters, such parameters includes: cost investment – Low technology greenhouses, medium technology greenhouses and high level greenhouse; based on shape – Lean-to, Even span, Uneven span, Ridge and furrow, Saw tooth, Quonset, Interlocking ridges and furrow type Quonset, Ground to ground; based on roof shape – Gothic, slant, saddle, round arch, hoop, gable, saw and flat; based on utility – active heating system, active cooling system; based on construction frames – Wooden framed, Pipe framed, Truss framed; based on covering materials – Glass, Plastic films, Rigid panel, shading net; based on cladding materials – Transparent glass, Fiberglass reinforced plastic/ polycarbonate, UV-stabilised low density polyethylene film; based on climate control mechanisms – naturally ventilated and forced ventilated. Generally, the structural components for greenhouse construction include framing, covering (cladding) materials, gutter, and foundation pipe, Bartok, 2000; Connellan, 2002; Tiwari, 2003; Samapika, *et al.* 2020; Rajender, *et al.* 2017; Montero, *et al.* 2013; Brian, *et al.* 2015; Kumar, *et al.* 2016; Waller and Yitayew, 2016 and Agricdemy, 2020; Cox, *et al.* 2010; FAO, 2011; Arora, 2012 and Castilla and Baeza, 2013. Figure 1 below shows the typical slanting roof shaped greenhouse with prominent parts labelled.

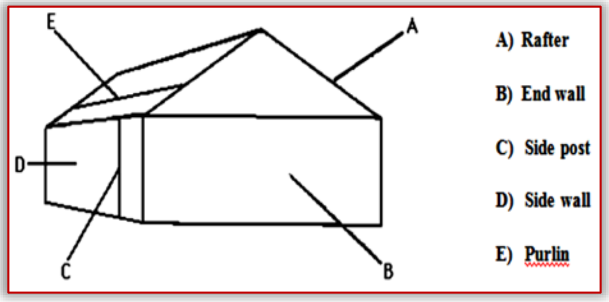


Figure 1: Primary components of a typical greenhouse. Source: Samapika, *et al.* 2020.

### — Greenhouse Development and Utilization

In Nigeria and elsewhere, Greenhouse farming is the business of working on and managing the growing of crops and plants inside a greenhouse. Akpenuun and Mijinyawa (2020) worked on split-gable greenhouse developed for tropical conditions and equipped with humidifiers and circulating fan for climate control. Five varieties of Irish potato were cultivated in- and outside the greenhouse in two rainy and dry seasons using three seedlings of each variety planted with 10 replicates using Completely Randomised Design (CRD). They concluded that climate data and yield in and outside the greenhouse differed significantly. In trying to establishing the potential of a greenhouse (GH) for the production of crops like irish potato in the tropics, Akpenuum and Mijinyawa (2018) showed that the yield and growth data in and outside the greenhouse were significantly different at 0.01. Mijinyawa and Osiade (2011) again conducted a survey in Oyo State aimed at establishing the present status of the use of greenhouse in the region. Infrequent research activities, prohibitive cost of construction and maintenance were among reasons given for the abandonment of most of the greenhouse studied in the region. The introduction of greenhouses in crop production was concluded to be one of the ways of combating the effects of climate change on crop production. Ale, *et al.* (2019) designed and constructed a greenhouse for the evaluation of the performance of Okra in the Sahel region of Ondo State, Nigeria. The evaluation process was carried out in the dry season to determine the effects of greenhouse and liquid organic fertilizer on the performance of Okra. Results revealed that greenhouse has potential to improve the growth performance Okra while inorganic fertilizer has no significant influence of the yield of okra fruit.

Omobowale and Sijuwade (2019) opined that greenhouse cultivation is highly influenced by the microclimate, which affects plant growth and development. Shading is an option for ensuring a relatively cool environment within tropical greenhouses which tends to heat up due to intense solar radiations. Omobowale and Sijuwade (2019) study was aimed at comparing the microclimate between a partially shaded greenhouse and unshaded one with respect to its effect on the crops. Cucumber (*Cucumis sativus*) and Okra (*Abelmoschus esculentus*) were grown in two greenhouses during the dry season of early 2018. One greenhouse was shaded with white coloured high-density polythelene film at the roof level while the other greenhouse was left unshaded. Both greenhouses were naturally ventilated. Results showed that shading had a positive effect on the growth compared to the okra parameter observed in the unshaded greenhouse as there was significant difference in the leaf length, leaf breadth, stem girth, plant height and yield (3.71±058 and 2.56±1.21 t/ha for shaded and unshaded respectively) at P< 0.05. There was significant difference in stem height of cucumber, as well as the incoming solar radiation at P< 0.05. Partial shading had minimal but positive effect on the crops.

Omobowale, (2020) reported that sustainable agriculture is critical towards paving a way for year-round production and supply of food. He observed that 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. To this, cultivation in controlled environments using functional and durable greenhouse structures presents an option. In Omobowale, (2020) study, a low-cost greenhouse was designed and constructed in Ibadan, Nigeria using locally available materials and 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 1 8° slope to allow easy drainage of rain water. Sweet pepper (Capsicum annuum, Cabernet) seeds procured from 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. He based their evaluation 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℃ and 91.1% respectively within the greenhouse in comparison with 29.7℃ and 89.7% respectively outside. Peak solar radiation was 413.4W/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. Omobowale, (2020) concluded that utilization of greenhouses in crop cultivation can help to mitigate the problem of food shortage.

The scope of greenhouse in Agricultural Engineering (cultivation, drying and space heating) was studied by Kumar *et al.,* 2006. They agreed that greenhouse provides control environment for high value crops like flowers, medicinal plants, etc. They also agreed that crops grown inside greenhouse are healthy and give better experimental results. They pointed out that latitude and crop requirements are two factors that the design of greenhouse depends on. Different heating and cooling arrangements could be done inside a greenhouse depending on crop requirements. They further emphasized that drying of crops, fruits, medicinal plants inside a greenhouse helps in reducing postharvest losses. Brian *et al.* (2015) opined that low cost design greenhouse and its innovation have the potential to contribute to increased food security, particularly in areas where global climate change is creating additional variability in local weather patterns. They described the preliminary design of a greenhouse that uses open source control Systems. This takes advantage of the decreasing cost and size of sensors to automate systems that have the potential to increase the efficiency and yield of greenhouses.

Sabin *et al.* (2020) verified the greenhouse roof-covering-material selection using the finite element method (FEM). Heating, Ventilation, and Air Conditioning (HVAC) were used to control the situations. They observed that the covering materials of several conventional greenhouses are manufactured using polyethylene, which exhibits a limitation with respect to temperature control for ensuring optimal plant growth. Conducting the experiment using three different covering material configurations, obtained results were verified using FEM. Castilla and Baeza (2013) held that site selection is a key factor for profitable and sustainable greenhouse production. They emphasized that the main factors determining location and site selection of a greenhouse production area are: cost of production, quality of produced yield, and transportation cost to markets. They observed further that during the warm season, especially in the Mediterranean and tropical areas, where there is high solar radiation and the temperature exceeds the recommended maximum threshold level, the greenhouse effect has an adverse impact on the microclimate and crop performance. Solar radiation is the main climate parameter needed to evaluate the climate suitability of a region for protected cultivation. Other climate parameters, such as soil temperature, wind, rainfall and air composition (humidity and $CO_2$), influence to a lesser degree the evaluation of climate suitability (Castilla and Baeza, 2013). They opined further that the following varieties of factors must be considered in locating a greenhouse: Topography, Microclimate, and Protection from cold wind; Irrigation water, Soil characteristics, flooded areas, Air pollution, Expansion, Labour availability, Communications network and Orientation

Two greenhouse models were identified by Montero *et al.*(2013) which were the active climate control (characterized by High yields, Good quality almost all year round, regular production and High costs) and passive climate control (characterized by Limited yields, Good quality in limited periods, Irregular production and Low costs).

There are numerous options available to greenhouse operators to minimize or eliminate risks related to locating greenhouse in temperate, subtropical and tropical climate zones, environmental modification techniques. The techniques are broadly categorized into: greenhouse design (shape, dimensions and roof configuration), reducing solar load through shading and venting, forced air circulation and evaporative cooling (Connellan, 2002).

FAO (2011) listed the factors to be considered in selecting the location of a greenhouse to include: Topography, Soils, Windbreaks, Water supply and quality, Electricity, Roadways and labour force. Two basic design of greenhouse exists, namely the *Quonset* and the *A-frame*. The Quonset is based on an arched roof that permits stresses on the structure to be efficiently transferred to the ground. Quonset greenhouses are normally available in two basic designs (FAO, 2011). FAO (2011) also listed greenhouse design parameters to include light, design load, foundation, Orientation, Size, and heights. The structural materials can be grouped into floors, frames and coverings. Floors may be constructed of porous concrete, Portland cement, gravel or compacted clay covered with a strong polypropylene fabric. Figure 2 below shows the slant roof type of greenhouse with base pavement (a special future) during construction at the department of Agricultural and Food Engineering, Faculty of Engineering, University of Uyo, Nigeria.

— General research trends in greenhouse technology

Different methodologies have been used for the analysis of greenhouse technology; both quantitative and qualitative. The principal results show that there are different relevant lines of research related to different aspects of greenhouse farming: the use of water for irrigation, the design of the optimum structure of the greenhouse, conserving the soil in the best growing conditions, energy consumption of the system as a whole, climate control within the facility and pest control, Jose, *et al.,* 2020; Teitel, *et al.,* 2012.


Figure 2: Stages in the development of Greenhouse coupled with the irrigation component, University of Uyo.

Cossua, *et al.* (2020)The integration of the photovoltaic (PV) energy in the greenhouse farm has raised concerns on the agricultural sustainability of this specific agrosystem in terms of crop planning and management, due to the shading cast by the PV panels on the canopy. The PV greenhouse (PVG) can be classified on the basis of the PV cover ratio (PVR) that is the ratio of the projected area of PV panels to the ground and the total greenhouse area. In this paper, we estimated the yield of 14 greenhouse horticultural and floricultural crops inside four commercial PVG types spread in southern Europe, with PVR ranging from 25 to 100%. The aim of the work is to identify the PVG types suitable for the cultivation of the considered species, based on the best trade-off between PV shading and crop production. The daily light integral (DLI) was used to compare the light scenarios inside the PVGs to the crop light requirements, and estimate the potential yield. The structures with a PVR of 25% were compatible with the cultivation of all considered species, including the high light demanding ones (tomato, cucumber, sweet pepper), with an estimated negligible or limited yield reduction (below 25%). The medium light species (such as asparagus) with an optimal DLI lower than 17 $molm^{-2}$ $d^{-1}$ and low light crops can be cultivated inside PVGs with a PVR up to 60%. Only low light demanding floricultural species with an optimal DLI lower than 10 $molm^{-2}$ $d^{-1}$, such as poinsettia, kalanchoe and dracaena, were compatible inside PVGs with a PVR up to 100%. Innovative cropping systems should be considered to overcome the penalizing light scenarios of the PVGs with high PVR, also implementing LED supplementary lighting. This paper contributes to identify the sustainable PVG types for the chosen species and the alternative crop managements in terms of transplantation period and precision agriculture techniques, aimed at increasing the crop productivity and adaptability inside the PVG agro-systems.

Kimura, *et al*. (2020) upheld that environmental controls in a greenhouse improve microclimates, thereby enhancing photosynthesis, but they create spatiotemporal non-uniformity of photosynthesis, with implications for unstable crop production. They noted that there has been no research focusing on the spatiotemporal variability of photosynthesis arising from greenhouse environmental controls. They therefore visualized spatiotemporal distributions of leaf photosynthetic rate (A) and assess its linkages with microclimates [air temperature (Ta), water vapour concentration (Wa), $CO_2$ concentration (Ca), and leaf-boundary-layer conductance (ga)] across a strawberry greenhouse during daytime under roof ventilation and $CO_2$ enrichment, using physical, physiological, and biochemical models for A and mobile observations of the microclimates. Kimura, *et al*. (2020) observed that the distributions of A varied during the daytime and were non-uniform across the greenhouse under the influence of the microclimate distributions arising from the environmental controls. With the roof ventilation in particular, spatial variations of Ta and ga were most associated with non-uniformity in A through the physical process of the energy budget determining the leaf temperature and thus affecting leaf physiological properties (photosynthetic capacities and stomatal conductance). With $CO_2$ enrichment, in addition to the roof ventilation, spatial variations of Ca further increased non-uniformity in A through large variations of Rubisco-limited and RuBP-limited rates in the biochemical process of leaf photosynthesis. Spatial non-uniformity of A arising from the environmental controls ranged from 15% to 69% during the daytime. These findings indicated the importance of considering the spatiotemporal variability of photosynthesis with respect to its physical, physiological, and biochemical processes, in addition to the benefits of microclimates, for optimizing greenhouse environmental controls, Kimura, *et al*. (2020).

Pack and Mehta (2012) reflecting on the severity of global food insecurity, over 60% of the East African population were considered malnourished, with many regions in a state of famine. They emphasised that there is broad agreement on the need to help small-scale farmers move from subsistence to sustainable and profitable farming by boosting their agricultural productivity, reducing post-harvest spoilage losses and providing market linkages. Greenhouses, they believed can help farmers in East Africa grow and protect crops in both wet and dry seasons. Since large commercial farms, many of them owned by multi-national corporations, employ greenhouses that span several acres of land to produce high-value cash crops including fruits, vegetables and flowers for the export market. United State Botanic Garden (USBG, 2013) stated that improved types of greenhouse, cladding/covering materials, location of greenhouse as a function of site orientation, light direction and ventilation, good site selection, hydroponic and traditional irrigation systems were opined to account for their perceived new trends in greenhouse development.

Asgharipour, *et al.,* 2020, observed that the use of energy to evaluate the sustainability of greenhouse systems leads to management recommendations to increase the sustainability of production in these systems. Four greenhouse systems one each for cucumber, tomato, bell pepper, and eggplant production, located in Jiroft city, Iran, were evaluated using energy sustainability indices. To accomplish this study, 56, 31, 19, and 12 greenhouses were selected for cucumber, tomato, bell pepper, and eggplant production, respectively. Analysis of twelve energy indices and a study of the social characteristics of the producers using Analytic Hierarchy Analysis (AHA) showed that the sustainability of the cucumber production system was greater than that of the other three systems. They reported the calculated unit energy values for economic yield (UEVE) generally indicated that greenhouse systems were at least 100 times more sustainable than open farm systems for the production of different products, primarily because of drastically reduced soil erosion. The highest (5.10E+04 sej $J^{-1}$ [4.96E+04, 5.25E+04]) and lowest (7.27E+03 sej $J^{-1}$ [7.09E+03, 7.45E+03]) UEVE values were calculated for the bell pepper and cucumber systems, respectively. Therefore, selection of a plant with more potential to use free local environmental energy, higher yield, and more efficient use of labor will lead to greater sustainability of greenhouse vegetable production systems. Sustainability can also be increased by paying attention to the sociotechnical characteristics of the producers, the use of technologies to reduce non-renewable inputs to the greenhouse building, and by reducing the proportion of non-renewable inputs used overall, Asgharipour, *et al.,* 2020.

Yilmaz, *et al.,* 2005 examined the current status of the Turkish greenhouse industry and highlights issues important for its competitiveness. The greenhouse industry was reported to be the fastest-growing segment of agriculture in Turkey, mainly because of favourable climatic conditions. They however observed that, in recent years the greenhouse industry has been forced to adopt an increasingly competitive place in the market. The competitive market environment for greenhouse produce does not necessarily provide growers with any assurances about sales volume, a sufficient price, or favourable financial outcome. Currently, greenhouse operators in Turkey are faced with problems such as declining crop prices, price fluctuations based on over-supply, poor market systems and sales uncertainty, and lack of grower cooperatives. These problems have resulted in income uncertainty and market risks for greenhouse operators. In addition, strong dependency on imported inputs and excessive use of chemicals are other weaknesses of the Turkish greenhouse industry, Yilmaz, *et al.,* 2005.

Yongguang, *et al.,* (2007) opined that a real-time environment information acquisition system is essential if models and vegetable-crop information are to be integrated with a greenhouse management expert system for good decision making. Their designed greenhouse management expert system has four functional modules: (1) cultivation techniques, (2) pest and disease diagnosis and prevention, (3) nutrient deficiency diagnosis and fertilisation, and (4) environment control. The hardware and software of the environment information acquisition system were incorporated into the expert system, which also offers a multi-interface for sensors and is easily extended and maintained. Implementation was accomplished with the whole system to ensure its reliability and applicability for expert system, on-line decision making. The results showed that a dynamic integration of a greenhouse management system and an environment information acquisition system can supply sufficient information for good control strategies and for decision-support.

In order to improve the yield and quality of greenhouse crops, it is necessary to develop a reliable model to predict and control the microclimate of greenhouse, Hua, *et al.,* 2019 studied the problem of deterministic and stochastic modelling for greenhouse microclimate defined by the variables of temperature and humidity. Experiments were conducted in a naturally ventilated single-sloped greenhouse without crops in north China. Firstly, a mechanism model was adopted and the assumed unknown parameters were derived by using increased convergence factor particle swarm optimization algorithm. Secondly, Hua, *et al.* (2019) considered disturbance as an independent identically distributed white noise, a stochastic dynamic model was constructed and the parameters were obtained by using maximum likelihood estimate. Finally, a comparison of measured and simulated data was given to show that the proposed models can reasonably forecast internal greenhouse microclimate.

— Adaptable Irrigation type for GH farming

For an effective irrigation delivery, the design must consider parameters such as available moisture, root zone depth, allowable moisture depletion, net peak water requirements, irrigation frequency and cycle, and irrigation efficiencies in order to calculate the design flow (FAO, 1989; 2008). The maximum amount of water to be supplied has to be determined using factors such as soil type, root depth and the irrigation method. Three simple methods in determining irrigation schedules are plant observation method (including determination of soil moisture content using gypsum blocks, tensiometers and neutron probes), estimation method and simple calculation method. Determination of irrigation schedule for a given crop could be based on the total growing period, based on the months of peak irrigation, or based on a combination of the two schedules above.

According to Waller and Yitayew (2016), irrigation methods are categorized into surface, subsurface and overhead (Figure 1). Subsurface drip irrigation saves water, improves crop yields and quality, and facilitates fertilizer application; however, system performance is dependent upon skilled management. Potential disadvantages include salt accumulation near plants, restricted root development, high system costs, and restricted crop rotation. The three primary hydraulic classifications of drip emitters are laminar, turbulent, and pressure compensating while Emitters are classified as laminar flow, turbulent, orifice, vortex, partially pressure compensating, or pressure compensating. The hydraulic relationship between pressure and flow is a function of the type of emitter. This relationship is given as:

$$q = Kh^x \quad (1)$$

where q is emitter discharge, h is operating pressure head, k is the emitter discharge coefficient, and x is the emitter discharge exponent. Making an informed estimate of the emitter spacing along the lateral, the spacing between laterals, the emitter flow rate and lateral length. While plant spacing, plant rooting characteristics, soil texture, and lateral hydraulics are the factors that determines the selection of emitters' spacing and flow rate. It is known that calculation of the soil water holding capacity is generally not required for drip irrigation systems because drip irrigation is a high frequency irrigation system with daily or even more frequent water application.

Localized irrigation is usually comprised of drip, micro-jet (jet Spray) and micro-sprinkler irrigation while the advantages of localized irrigation system over others include: reduction in the evaporative component of evapotranspiration, reduction in weed growth due to limited wetted areas, penetration of water into problematic soil is improved by the slow rate of water application, and localized irrigation is considered as a water-saving technology. The probable disadvantages of the system include it's being prone to clogging because of very small aperture of the water emitting devices, movement of salts to the fringe of wetted area of the soil which may cause salinity problems through the leaching of salts by rain to the main root volume, the lateral lines can be damaged by rodents, dogs and other animals in search of water, not economical for the crops with very high population density due to large numbers of laterals and emitters required (James, 1993; FAO – SAFR, 2002; Grag, 2007; Arora, 2012).

Greenhouse crops are irrigated by means of applying water to the media surface through drip tubes or tapes, by hand using a hose, overhead sprinklers and booms or by applying water through the bottom of the container through sub-irrigation, or by using a combination of these delivery systems. Overhead sprinklers and hand watering have a tendency to "waste" water and also wet the foliage, which increases the potential for diseases and injury. Drip and sub-irrigation systems are the most efficient and provide greater control over the amount of water applied. Also, since the foliage does not become wet there is a reduced potential for diseases and injury, Douglas, *et al.,* 2010.

Babatunde and Mofoke (2006), explored the possibility of growing roselle (*Hibiscus sabdarriffa*. L) under irrigation without greenhouse component. The experimental treatments comprised of five irrigation schedules with irrigation intervals (*f*) of 3, 5, 7, 9, and 11 days. The corresponding gross water requirements (GWR) were 37, 56, 74, 93, and 112mm. The crops were grown under check basin irrigation during the 2001/2002 and 2002/2003 irrigation seasons in Bauchi state, Nigeria. Results showed that difference in number of leaves per plant was significant ($p = 0.05$) with the fifth irrigation schedule ($f = 11$ days, GWR = 112mm) giving the highest value of 347 leaves per plant, while the first irrigation schedule ($f = 3$ days, GWR = 37mm) resulted in only 192 leaves per plant. Variations in plant height, number of branches per plant and canopy diameter were insignificant ($p = 0.05$). The influence of irrigation schedule on the yield of Roselle measured with respect to fresh calyx weight was highly significant with a strong coefficient of determination of 97.1%. Yield soared with increase in seasonal irrigation depth, Babatunde and Mofoke, 2006. The increase followed a second degree polynomial, reaching a projected maximum of about 682 Kg/ha. The associated maximum seasonal application depth was found to be approximately 3389 mm. Results of this study indicate that maximum yield of roselle grown under irrigation could be attained with a weekly irrigation interval and a gross application depth of 188 mm.

Micro irrigation system is the best way for watering plants in a polyhouse as per the daily needs and the stage of the crop (Babatunde and Mofoke, 2006, Douglas, *et al.,* 2010, Teitel, *et al.,* 2012, Hochmuth and Hochmuth, 2018). Besides this, care should be taken that water does not trickle directly on the leaves or the flower, which may lead to disease and scorching of leaves or flowers. Fertigation equipment for providing fertilisers to the plants as per their daily needs, water-soluble or liquid fertilisers are injected in the irrigation mainlines feeding the greenhouse crops. Fertiliser dosers and tanks are used for injecting soluble fertilisers. They can also be connected to automatic mixing and dispensing unit. The fertilisers are dissolved in different tanks as per compatibility and are mixed in discrete proportions for supply to the plants through drip irrigation systems. The spraying system is used for spraying required chemicals on the crop to control pests and diseases, if any, Douglas, *et al.,* 2010, Teitel, *et al.,* 2012, Hochmuth and Hochmuth (2018),. The spraying machines are normally portable but may be equipped with high pressure motorised piston pumps and nozzles. For removing hot air from the greenhouses in forced ventilated greenhouses, cooling pads are used for cooling the air entering into the greenhouses. These systems are operated as and when the climatic parameters like temperature, humidity, etc., inside the greenhouse need manipulation as per crop growth requirement, Babatunde and Mofoke, 2006, Douglas, *et al.,* 2010. These are used for controlling light intensity falling on the crops inside the greenhouse. Various shading nets with shading capacities like 35 per cent, 50 per cent, 75 per cent are used for different crops and seasons. Sensors and Controllers they are used for controlling climatic parameters automatically inside hi-tech greenhouses. These systems are generally used for very high-value crops and sensitive activities like soil-less cultivation, tissue culture plant and hardening activities, Teitel, *et al.,* 2012.

Hochmuth and Hochmuth (2018) agreed that in a rockwool or perlite house, water enters the house directly from the well, is mixed with fertilizer stocks by proportioners or injectors and applied to each plant via drip or micro-irrigation emitters. A backflow prevention system (check valve, pressure relief, and low pressure drain) are required for systems in which fertilizer will be injected, Douglas, et al., 2010, Teitel, et al., 2012. The water from the well should be filtered (150 mesh) to prevent damage to the fertilizer proportioners. A union connection installed before all major components will allow them to be removed for maintenance. Proportioners usually operate on a pressure differential basis so that installation in parallel is probably preferred over series. They upheld that nutrient solution should be filtered (150 mesh) prior to application to the plants and that a pressure regulator should be installed to ensure the desired pressure in the greenhouse irrigation system. They concluded that Rockwool or perlite media receive water from individual emitters placed at the base of each plant enabling that each plant is irrigated from a short.

## DESIGN CRITERIA FOR GREENHOUSE

Rajender, *et al.* (2017) maintained that the cultivar growing technology under the low cost greenhouse is assuming an important role in Indian Agriculture in the future years. The low cost greenhouse ensures the year round growing of different cultivar varieties. This is to ensure timely availability of cultivars with good vigour. In his study, to establish a poly house, the farmer was reported to have invest between Rs.900-1000 for one $m^2$ area using tubular framed structure. To reduce the installation rate of greenhouses, a low cost greenhouse having an area of 50 $m^2$ was constructed (10 m × 5 m × 3.5 m) with locally available casuarina wood coated with coal tar was used as structural material and bamboos were used as frame work. Wooden strips with nails were used to make the poly grip assembly. UV stabilized PVC transparent sheet was used as outer cover in place of traditional glass sheets. The drip system was installed and costs around Rs. 23811.16/-.The cost for $m^2$ area is around Rs. 467.6/-, whereas to construct a greenhouse for naturally ventilated tubular structure is Rs 1060/- per $m^2$ (MIDH). So the cost was reduced to about 56 % by using locally available material.

Hochmuth and Hochmuth (2018), Bucklin, (2020), presented suggestions and options for designing and operating a greenhouse for vegetable production in perlite or rockwool. Their suggestions are presented for growers who desire to change their nutrient film technique (NFT)-pipe house over to solid media such as perlite or rockwool media. Their recommendations also would apply to other media, such as peat or pine park mixes. Their major considerations are those pertaining to the floor design for the media system. They, in addition presented suggestions for general greenhouse design and operation for tomato culture. Many of these suggestions would apply to houses with other production systems, e.g., upright bag or trough, and in most cases would be applicable for cucumbers, eggplant, and pepper. Included in their work were details on crop culture (irrigation, fertilization, disease and insect control, etc.) which can be found at the Florida Greenhouse Vegetable Production handbook.

Sutar (2020), position basically focused on the local climate and the bioclimatic requirements of the species to be cultivated, once the proper site has been selected, it will be necessary to choose the cladding material, the type of structure and the architectural shape of the greenhouse. He further opined that if the predictable climate generated by the greenhouse is not appropriate complementary facilities and equipment for, climate control will have to be considered. He upheld that greenhouse design is very much influenced, in practice, by the local climate and the latitude of the site, and in many cases is limited by the availability of materials for the construction. He agrees that no design is perfect, thus it is necessary to prioritize in each case, the criteria to follow, these being: the maximization of the light, minimizing, if possible, the structural elements to avoid shadows, ensuring good insulation which decrease the heat losses and affordable costs.

## TRENDS IN SMART GREENHOUSE / FARMING TECHNOLOGY

IoT is a new and upcoming trend in technology that finds its application in almost every field. Things, when connected to the internet and to each other, make the entire system smart. Ratnaparkhi, *et al.,* 2020 used IoT in every way of life: Smart Cities, Smart homes, Smart retail and many more. Using IoT in agriculture and farming practises is the need of the hour as the global population will hit a peak of 9.6 billion by 2050, to meet that kind of demand the agriculture industry needs to supply at an even faster rate. This feat can be achieved by using modern technology and mainly IoT, Ratnaparkhi, *et al.,* 2020. IoT makes labour free farms a possibility. Not only in major farming practices but it can also be used in maintaining livestock, greenhouse farming, managing farms etc. The most important tool used for IoT is Sensors, sensors are devices that collect essential data which is interpreted to get the desired analysis. For agriculture, sensors are mainly used to get readings used to measure NPK values, detect diseases and moisture content in the soil. Ratnaparkhi, *et al.,* 2020 in their study, explores its application in the agricultural sectors. Smart agriculture is called precision agriculture because it uses precise data to reach conclusions. It shows the various sensors which aid IoT and agriculture, their applications, challenges, advantages and disadvantages.

Kodali, *et al.* (2016) worked primarily on the improvement of current agricultural practices by using modern technologies for better yield. Their study produced a model of a smart greenhouse, which helps the farmers to carry out the work in a farm automatically without the use of much manual inspection. The irrigation of study plot was carried out using automatic drip irrigation, which operates according to the soil moisture threshold set accordingly so as optimal amount of water is applied to the plants. Based on data from soil health card, proper amount of nitrogen, phosphorus, potassium and other minerals were applied by using drip fertigation techniques. Proper water management tanks were constructed and filled with water after measuring the current water level using an ultrasonic sensor. Plants were also provided the requisite wavelength light during the night using growing lights. Temperature and air humidity were controlled by humidity and temperature sensors and a fogger was used to control the same. A tube well is controlled using GSM module (missed call or sms). Bee-hive boxes were deployed for pollination and boxes were monitored using ultrasonic sensors to measure honey and send mails to the buyers when they were filled. Further, the readings collected from storage containers are uploaded to cloud service (Google drive) and forwarded to an e-commerce company.

The Internet-of-Things (IoT) has reshaped the smart agriculture by not only given a boost to the productivity and optimized the resources, but it has also increased the efficiency and has minimized the cost of production, Tripathy, *et al.* (2020). Tripathy, *et al.* (2020) emphasised the potential of sensors and IoT in the field of greenhouse farming and presents the future of automation. The different parameters such as humidity, water nutrients solution level, pH and EC value, temperature, UV light intensity, $CO_2$ level, mist, and amount of insecticides or pesticides were monitored in their study through various sensors so that significant knowledge about the early fault detection and diagnosis can be done. A Decision Support System (DSS) presented in their study acts as the central operating system which governs and coordinates all the activities. Furthermore, their study also accounts for the different challenges of greenhouse Rose farming and highlights a new IoT based solution which is smart and sustainable. The model presented in study is well adapted to the changing environment, thereby redefining the terms of sustainability, Tripathy, *et al.* (2020).

Wang and Yu (2019) reported the influence of science and technology, in the progressive development of modern agricultural technology in China. The research of intelligent greenhouse control system has far-reaching significance. Wang and Yu (2019) believed that greenhouse control system should meet the function demands of data acquisition, data transmission and remote monitoring. In their study, the overall control structure of greenhouse was formulated within the framework of Internet of Things (IoT) technology, which is divided into perception layer, transmission layer and application layer. Based on the architecture of IoT and Zig Bee wireless sensor network technology, Wang and Yu (2019) designed four modules of the control system, including login management module, data display module, remote control module and system management module. The greenhouse control system of IoT was tested and analysed and the experimental results show that the system can achieve the expected effect of greenhouse.

Fedotova, *et al.,* 2020 assessed the current state of Russia's agricultural sectors in the context of restrictive sanctions and food embargo. Their attention focused on the need to intensify the production of agricultural raw materials for domestic consumption and export to the world market; while noting the low efficiency of the main branches of the agro-industrial complex in Russia. The experience of developed countries revealed that the implementation of advanced information technologies into traditional agro-business processes makes it possible to increase the profitability of agricultural sectors. The development of electronic technologies, implementation of automated data collection devices and processing of the results obtained contribute to the implementation of the Industry 4.0 concept in the transition to an information society. Fedotova, *et al.,* 2020 analyzed the developed Federal Scientific and Technical Program (FS&TP) for the Development of Agriculture for 2017–2025 being implemented. Fedotova, *et al.,* 2020 conducted their study using the generalization and analog methods, statistical and graphical analysis, vertical and horizontal analysis and methods of data comparison and collation. Their finding showed that today 3 activities are being financed in Russia, i.e., the creation of scientific and technical results and products; implementation of scientific and technical results and products into production; and commoditization of scientific and technological results and products. Based on these areas, the main trends of scientific and technological development of agriculture were identified to include "smart farm," "smart greenhouse" and "smart field." The introduction of these trends into the practice of agricultural organizations will enable meeting the basic needs of the domestic food market and increasing the volume of exported agricultural products as well as provide an opportunity to increase profitability and intensify the initiative to create "smart enterprises" in the agricultural sector.

Katzin, *et al.,* 2020 opined that Greenhouse models are important tools for the analysis and design of greenhouse systems and for offering decision support to growers. While many models are available, relatively few include the influence of supplementary lighting on the greenhouse climate and crop. Katzin, *et al.,* 2020 worked on GreenLight, as a model for greenhouses with supplemental lighting. GreenLight extends state of the art models by describing the qualitative difference between the common lighting system of high-pressure sodium (HPS) lamps, and the newest technology for horticultural lighting - the light-emitting diodes (LEDs). LEDs differ from HPS lamps in that they operate at lower temperatures, emit mostly convective heat and relatively little radiative heat, and can be more efficient in converting electricity to photosynthetically active radiation (PAR). These differences can have major implications on the greenhouse climate and operation, and on the amount of heat that must be supplied from the greenhouse heating system. Model predictions have been evaluated against data collected in greenhouse compartments equipped with HPS and LED lamps. The model predicted the greenhouse's heating needs with an error of 8 - 51$Wm^{-2}$, representing 1 - 12% of the measured values; the RMSE for indoor temperature was 1.74 - 2.04$^0$C; and the RMSE for relative humidity was 5.52 - 8.5%. It is hoped that it may be further evaluated and used by researchers worldwide to analyse the influence of the most recent lighting technologies on greenhouse climate control, Katzin, *et al.,* 2020.

Chen, *et al.* (2020) noted that Internet of things (IoT) technology has been constantly applied in greenhouse environmental monitoring and control in recent years. The acquisition and control parameters, network protocols are different for the various purposes of the greenhouse. These factors are the keys to the abilities to effectively communicate and transfer meaningful data in IoT infrastructures. To achieve the adaptive matching of data communication between the gateway and server in a greenhouse IoT system, Chen, *et al.* (2020) designed a data encapsulation method based on XML to enable data interoperability in a distributed greenhouse IoT system. They further used the behaviour of the Multi-Agent System (MAS) to merge the heterogeneous information and the responses for data synchronization in the greenhouse IoT system, Chen, *et al.* (2020). The data communication mechanism for real-time and cumulative data synchronization between the gateway and server based on JADE was tested in a specific greenhouse. The results showed that the data loss rate between the data acquisition unit and the gateway was 1.52%, and the data loss rate was 0.4% between the gateway and the server; therefore, the mechanism could be feasibly applied to the data communication for a greenhouse IoT system, Chen, *et al.* (2020).

## CONCLUSIONS & RECOMMENDATION

Greenhouse technology in agriculture for research and commercial production purposes has been in existence and continues to be useful in the production and study of choice plants; prevented from the influence of the environment and effects of diseases and pests. Literature support the employment of greenhouses coupled with the appropriate irrigation systems in the study and production of any selected crop(s). The plants cultivated in greenhouses fall into several broad categories based on their temperature requirements during nighttime hours. In a cool greenhouse, the nighttime temperature fall to about 7–10ºC. Among the plants that thrive in cool greenhouse are azaleas, cinerarias, cyclamens, carnations, fuchsias, geraniums, sweet peas, snapdragons and various types of bulbous plants like daffodils, irises, tulips, hyacinths and narcissi. A warm greenhouse has nighttime temperatures of 10–13ºC. Begonias, gloxinias, African violets, orchids, roses and many kinds of ferns, cacti and other succulents are adaptable to such temperatures. In the tropics, greenhouse has nighttime temperature of 16–21ºC, variety of palms and orchids can be grown, Rajender, *et al.* (2017)

Greenhouse has evolved from its status as it was in the 17$^{th}$ century to current trend of incorporating ITC, IoT, and Drone, generally termed smart farming. The common disadvantage of drudgery, timelineness, accuracy and precision, etc hitherto witnessed in greenhouse farming have been transformed to become advantageous features through current technology trends. Further still, greenhouse phenomenon has bring farming closer to man by the ease with which vegetable crops could be grown and produce to commercial level when technology (ICT, IoT, Drone and Hydroponic) are combined. Definition of greenhouse and the required optimum operational environments were discussed in line with greenhouse development and utilization in Nigeria and globally. Types of existing greenhouses, classifications, component parts, materials used for it construction, etc were reviewed. General research trends in greenhouse technology, irrigation as source of water supply for greenhouse farming, design criteria for greenhouses and trends in smart greenhouse technology were all reviewed. The results so obtained from the study could be a source
of information to assisting stakeholders like farmers and the government who may be interested in commercializing the production and processing of Zobo into desired end products in the agricultural value chain.

The following recommendation is suggested based on the information derived from reviewed literature and the knowledge gap such review provides:

I. Usage of GH should be encouraged extensively in Africa and in Nigeria in particular. This will provide enough vegetative crops to make up for the obvious deficit in the production chain, in order to meet the soaring demand
II. Use of GH for practical purposes in higher institutions and research institutes should be enforced by relevant government to inform farmers and stakeholders alike on the importance of GH and its utilization in bridging the supply gap in vegetation production chain.
III. The application of ICT, IoT, Drone, Robotics, Hydroponic and other daily emerging technologies should be publicize in order to improve yields to meet food demand, eliminate drudgery, save time, making farming to the teaming youths in Africa, etc.
IV. Larger and Commercial GH should be encouraged in order to improve the environment and reduce incidence of all forms of environmental degradations.

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