IMPACT OF A SPLIT-GABLE GREENHOUSE MICROCLIMATE ON THE YIELD OF IRISH POTATO (*SOLANUM TUBEROSUM L.*) UNDER TROPICAL CONDITIONS

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ABSTRACT

Production of Irish potato is limited to a temperate climate. Increasing demand for this crop has necessitated the introduction of other production options. A possible option is the use of controlled environment agriculture. This study was designed to investigate split-gable greenhouse microclimatic conditions for Irish potato production under tropical conditions. The split-gable greenhouse was developed for tropical conditions and equipped with humidifiers and circulating fan for climate control. Data loggers and a weather station were installed in- and outside the greenhouse to monitor the climate. Five varieties of Irish potato (Nicola, Diamant, Bertita, New seed, Okonkwo) were cultivated in- and outside the greenhouse in two rainy- and dry- seasons. Three seedlings of each variety were planted with 10 replicates using Completely Randomised Design (CRD). The air temperature, Relative Humidity (RH) and Vapour Pressure Deficit (VPD)of the greenhouse were measured in accordance with standard procedures. Yield obtained were compared with standard yield values. Data were subjected to regression analysis and ANOVA at $\alpha_{0.05}$.Greenhouse floor, wall, roof, glazing, ventilation area and volume were 48.0, 84.0, 52.4, 108.4, 32.8 m^2 and 175.4 m^3, respectively. The humidifier and fan had capacities 7.4 g of H_2O/kg of air.h and 2.5 m^3/s air flow rate, respectively. The thickness and light transmittance of the glazing material was 2 mm and 75%, respectively. The pitches, rises and pitch angles of the split-gable roof were 0.3/0.2, 1.6/1.0 m and 15.1°/9.7°, respectively. Rainy season temperature, RH and VPD were 23.6±1.1°C, 82.3±2.8% and 0.5±0.1 kPa, respectively inside the greenhouse compared with 29.3±1.2°C, 78.5±7.3% and 1.2±0.2 kPa outside the greenhouse. Dry season temperature, RH and VPD were 25.5±2.7°C, 75.3±2.4% and 0.7±0.3 kPa, respectively inside the greenhouse compared with 36.1±1.9°C, 63.12±10.4% and 2.2±0.7 kPa, respectively outside the greenhouse. Greenhouse microclimatic conditions were within the reported threshold of 15-35°C, 70-85% and 0.4-1.0 kPa necessary for potato production. Bertita and

New seed had the highest yield of 6.4 and 6.1 kgm^{-2}, respectively in rainy season and 5.3 and 5.4 kgm^{-2}, respectively in the dry season inside the greenhouse. New seed gave the highest yield of 1.7 kgm^{-2} outside the greenhouse both in rainy- and dry- seasons, while Okonkwo had the least 0.2 kgm^{-2} outside the greenhouse in dry season. Reported equivalent mean yield in au State for the five varieties were in the range 7.6-11.3 kgm^{-2}. Climatic data and yield in- and out- side the greenhouse differed significantly. Temperature, RH and VPD had significant interactions with yield. A split-gable greenhouse that provided suitable microclimatic conditions for Irish potato production in tropical conditions was developed.

Keywords: Split-gable greenhouse, Controlled environment agriculture, Irish potato, climate, glazing

1.0 INTRODUCTION

Controlled Environment Agriculture (CEA) is an integrated science and engineering-based approach that provides favourable environmental conditions for crop production while optimising resources such as land, capital, labour, equipment, water and energy(Kacira, 2012). Controlled environment agriculture is a subject nested within the broader agenda of optimising the food system, to deal with forthcoming changes in population and climate change. Controlled Environment Agriculture (CEA), also known as protected agriculture, is defined as an integrated science and engineering-based approach, which provides the most favourable environmental conditions for plant productivity, while optimizing resources such as water, energy, space, capital, labour, plant growing systems, plant quality and production efficiency (Giacomelli, 2013; Shamshiri *et al.*, 2018; Akpenpuun and Mijinyawa, 2018). FAO (2015) controlled environment agriculture as any agricultural technology that enables the manipulation of an environment to the desired requirements of a crop. CEA technologies protect crops and allow the control of environmental parameters such as temperature, light intensity, photoperiod, humidity, pH, vapour pressure deficit (VPD), nutrient and carbon dioxide (CO_2). The technologies allow cost-effective year-round production of high-quality edible, ornamental and high-value plant species(Mijinyawa, 2011; Giacomelli, 2013).

Irish potato is a starchy tuberous crop from *Solanum tuberosum* of the *Solanaceae* family, and it is cultivated for food and industrial raw material. Irish potato is a highly cherished food crop worldwide, but its cultivation is limited to certain areas by climatic requirements(Jwanya *et al.*, 2014). Irish potato has a short growing cycle of between 60 to 90 days giving it the advantage of being cultivated two to three times a year as compared to 270 and 360 days for yam and cassava respectively, which are cultivated once a year (Jwanya, 2014; Akpenpuun and Mijinyawa, 2018). Nicola, Bertita, Okonkwo, Diamant, New Seed, Desiree, Rsolin Ruaka, Greta and Br6-18 originate from Holland, Mexico, Nigeria, Holland, Nigeria, Holland, Kenya, Greta and USA, respectively (Okonkwo *et al.*, 2009). Irish potato is the fourth largest cultivated food crop in the world after wheat, rice, and maize(FAOSTAT, 2014). It is an important source of food, income and employment in developing countries because of its high-energy content and ease of production (Wuyep *et al.*, 2013; Zemba *et al.*, 2013). World production of Irish potato as of 2013 was 368 million tonnes with Nigeria contributing 1,200,000 tonnes (FAO, 2008; Jwanya, 2014).

Despite the numerous importance of Irish potato, not much effort hasbeen made towards promoting its cultivation in the tropical regions. Although, Okonkwo *et al.* (2009) and Zemba *et al.* (2013)have carried out studies on Irish potato their interest was mainly on developing high-yielding and disease-resistant varieties and the agronomic properties such as yield, flowering behaviour, development and vegetative growth. These studies succeeded in developing high-yielding and disease-resistant varieties of Irish potato, but not much has been done on the possibility of having Irish potato cultivated in other parts of the country to increase the volume of production required to meet the increasing demand(Jwanya *et al.*, 2014). This has necessitated the need to explore other possible areas and technologies for the cultivation of Irish potato in Nigeria. One of the many options that could be exploited in bridging the gap between the demand and supply is the adoption of technologies that could expand the area where the crop can be cultivated within the country. Controlled Environment Agriculture (CEA) using the greenhouse is one of such possible approaches especially as the ambient climatic conditions in many parts of the country constitute the limiting factor to the expansion of its cultivation (Mijinyawa, 2011). The successful adoption and utilization of CEA will ultimately increase the area of cultivation and expectedly increase the volume of production and reduce the demand-supply gap. The objective of this research was to investigate and establish the potentials of a split-gable greenhouse to enhance Irish potato production under the tropical conditions

2.0 MATERIAL AND METHODS

2.1 Study area

This study was carried out at Ilorin town in the Ilorin-South Local Government Area of Kwara State, Nigeria. Ilorin lies between latitudes 8º30' and 8º50'N of the Equator and longitudes 4º20' and 4º35'E of the Greenwich Meridian and at an altitude of about 304 m above the mean sea level. Ilorin city occupies an area of about 468 sq. km and is situated in the transitional zone within the forest and the guinea savannah regions of Nigeria. Kwara State is located in the North-Central part of Nigeria and lies in the region termed the Middle Belt. It is located in the Southern Guinea Savannah and enjoys moderate dry and wet seasons. Kwara State has an elongated shape covering an area of about 32,500 sq. km. The state is bounded by River Niger to its northern and eastern margins and shares a common internal boundary with Kogi State to the east, Oyo, Ekiti and Osun States to the south and an international boundary with the Republic of Benin to the west. The soils of Ilorin are loamy and clay (Ejieji, 2011; Akpenpuun and Busari, 2017). The climate of Ilorin is tropical with annual rainfall, maximum temperature, relative humidity and the daily photoperiod of 1500 mm, 38 ^{o}C, 77.50 % and 7.1 hours respectively (Olanrewaju, 2012). The rainy season begins in late March and ends in early September while the dry season begins late September and ends in early March. Food crops cultivated in the state include yam, cassava, sweet potato, groundnut, sorghum, millet, maize and cowpea (Ajadi *et al*., 2011).

2.2 Framing members

Although there are several possible materials for the greenhouse construction, however, timber was selected for the construction. The selection of timber as the material of construction was based on workability, availability, and cost. All structural members were obtained from Red Ironwood (Ekki / *Lophira alata*) and the strength properties (N1) were obtained from the Nigerian Code of Practice for the Structural Use of Timber (Nigerian Industrial Standard, 2005).

2.3 Greenhouse shape and greenhouse orientation

The split gable roof greenhouse design was adapted as it is the most suitable greenhouse design for the tropics because it allows creation of a convection system of air exchange through the split gable and the gable provides ample aerial space for adequate ventilation. The choice of North-South structure orientation was determined by the quantity, duration and uniformity of solar radiation required within the structure for plant growth and development.

2.4 Greenhouse ventilation requirement

It has been established that pressure drop on ventilation openings due to screens is mainly a function of screen porosityKittas *et al.* (2013). In this context, 30% of the greenhouse floor area was vented on the walls and ridge as recommended by ANSI/ASAE EP406.4 standards ASAE (2013).

2.5 Structural analysis

The roof dead load consisted of the weight of the covering material on the roof (polyethene) and trusses. From experience and common practice, a 50 x 50, 50 x 75 and 50 x 100 mm lumber sizes are adequate for roof frame construction. However, 50 x 100 mm lumber was used for the construction for greater strength and stability. Figures 1 - 3 show the end, side and Isometric views of the split-gable greenhouse. Assuming that the columns were fixed at the bottom and pinned at the top. The effective length was determined as shown:

$$\text{Moment of inertia, I} = \frac{bd^3}{12} \qquad 5$$

$$\text{Buckling load, } \mathrm{P_b} = \frac{\pi^2 \mathrm{EI}}{0.7\mathrm{L}^2} \qquad 6$$

$$\text{Crushing load, } \mathrm{P_{cr}} = \mathrm{f_c}.A$$

The Euler's buckling (264kN) and crushing (270kN) load of the columns are greater than the imposed load (316.7 N) from the roof.

The footing was designed in accordance with ACI 318-05 (2003).The imposed pressure (15655.3 Nm^{-2}) due to service load and weight of footing is less than the safe bearing capacity (22430 Nm^{-2}) of the soil. This value (15655.3 Nm^{-2}) of imposed pressure on the footings shows that the structure will be stable in service. The geometric specifications of the experimental greenhouse were: height of ridge opening, height of greenhouse, length of greenhouse, width of greenhouse and width of side openings 0.6, 3, 8, 6 and 1 m, respectively.

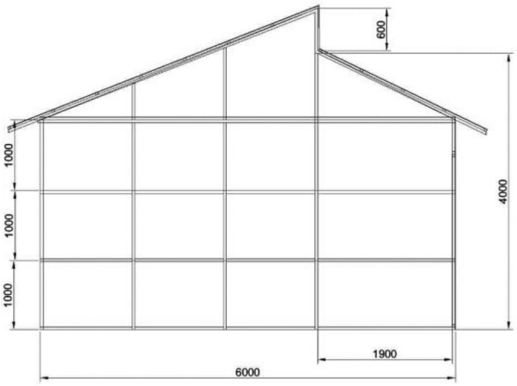


Figure 1: End View of the Greenhouse

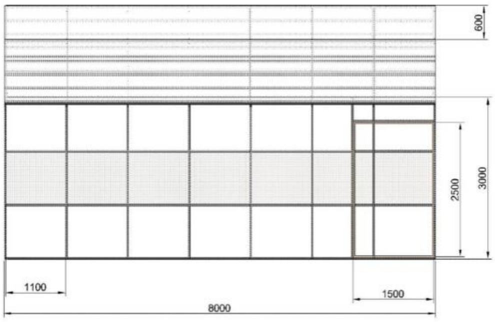


Figure 2: Side View of the Greenhouse

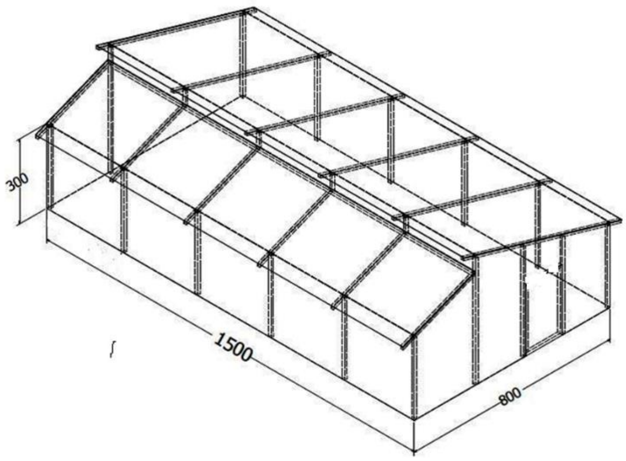


Figure 3: Isometric View of the Greenhouse

2.6 Greenhouse equipment and datarecording

The greenhouse environment was controlled using a humidifying system, circulating fan and natural ventilation. The humidifier had the capacity of introducing 0.12 m^3 (120 litres) of water into the greenhouse atmosphere in 30 minutes and had a power rating of 170 W.Lascar EL - WIFI Thermo-Hygrometer Data Loggers were installed to measured air temperature, relative humidity and dew point temperature of the greenhouse microclimate minutely. Four Loggers were installed in the greenhouse at a height of 1m above the ground.A mini weather station was installed outside the greenhouse to record the ambient atmospheric weather condition and was mounted at the ridge of the greenhouse for maximum exposure.The temperature and relative humidity data were then averaged to obtained daily means which were used to determine vapour pressure deficit (VPD) using equations 1– 3(Abd-El Baky *et al.*, 2004).

$$\text{Actual Vapour Pressure(kPa)}, e_a = e^o(T_{dpT}) = 0.611 \exp\left[\frac{17.27T_{dpT}}{T_{dpT}+237.3}\right] \quad 1$$

$$\text{Saturated Vapour Pressure (kPa)}, e_s = e^o(T) = 0.611\exp\left[\frac{17.27T}{T+237.3}\right] \quad 2$$

$$\text{Vapour Pressure Deficit} = e_s - e_a \quad 3$$

2.7 Experimental design

Two experiments were carried out in four seasons in- and out- side the greenhouse. The rainy season experiment was carried out in the months of August 2015 to October 2015 and April 2017 to June 2017, while the dry season experiment was in the months of December 2015 to March 2016 and October 2016 to December 2016.The experimental design method applied during planting of the potato seedlings in- and out- side the greenhouse in the two experiments was the completely randomized experimental design (CRD). Three seedlings of each variety (Nicola, Bertita, Diamant, Okonkwo and New Seed) were planted using completely randomised design with 10 replicates in each season. The air temperature, Relative Humidity (RH), Vapour Pressure Deficit (VPD) and Day Light Integral (DLI) of the greenhouse were determined in accordance with standard procedures. The data obtained was subjected to the analysis of variance, regression analysis and Tukey's Honest Significant Difference (HSD) test using STATA (Version 4.2.2) and Statistical Package for Social Sciences (SPSS version 6.0).

2.8 Potato yield

Potato tubers from Nicola, Bertita Diamant, Okonkwo and New Seed varieties both in- and out- side the greenhouse at maturity were harvested. The potato tubers from each of the varieties of Irish potato were collected and were weighed differently using a digital weighing balance in order to determine the total yield in gramme (g) and the yield per area in gramme per metre square (g/m^2).

3.0 RESULTS AND DISCUSSION

3.1 Greenhouse performance

The greenhouse was evaluated in terms of micro-climate regulation comprising air temperature, relative humidity (RH) and vapour pressure deficit (VPD) and crop yield.

3.2 Air Temperature

The temperatures obtained in the rainy- and dry- seasons in the experiments showed that the greenhouse temperature in the rainy season was in the range of 21.4 to 28 ^{o}C, while outside the greenhouse the temperature was in the range of 26.5 to 36.3 ^{o}C. The greenhouse temperature in the dry season experiment varied between 21.3 and 31.8 ^{o}C, while outside the greenhouse the temperature ranged from 29.2 to 40 ^{o}C. The trends of temperature recorded in- and out- side the greenhouse in the rainy- and dry- season experiments are as presented in Figures 4 and 5. The greenhouse temperature range was within the required temperature boundary for successful Irish potato production only in a few instances that the greenhouse temperature was above the temperature boundary in the dry season.

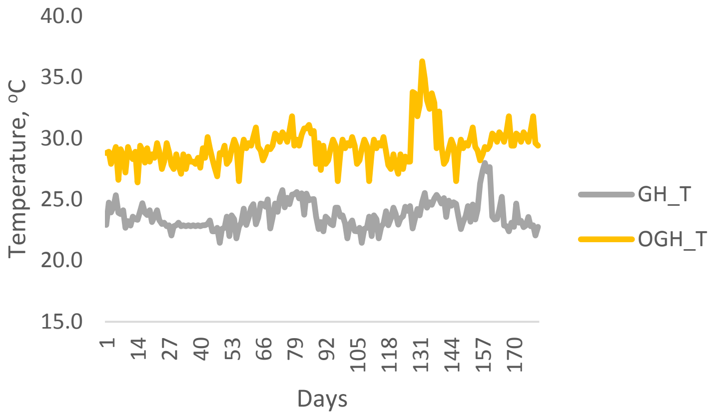


Figure 4: Temperature Fluctuations In- and out- side Greenhouse in the Rainy Season

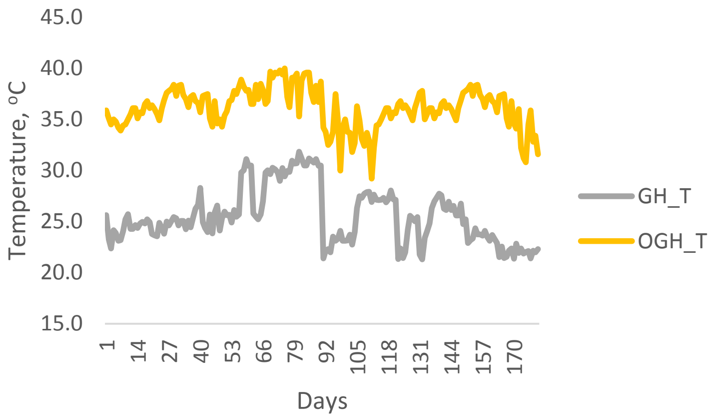


Figure 5: Temperature Fluctuations In- and out- side the Greenhouse in the Dry Season

GH_T: temperature inside the greenhouse, OGH_T: temperature outside the greenhouse

The mean temperature recorded in- and out- side the greenhouse was 23.6±1.13 and 29.3±1.51^{o}C in the rainy respectively, while in the dry season the mean temperature in- and out- side the greenhouse was 25.5±2.73 and 36.1±1.98 ^{o}C respectively. In the dry season, outside the greenhouse the temperature was above the maximum recommended temperature value of 35 ^{o}C required for Irish potato growth and development. However, the temperatures inside the greenhouse was most often within the required temperature range of 18 and 35 ^{o}C in both experiments.

Temperature differences in the range 5.1 – 8.3 °C and 7.9 °C – 9.2 °C were observed between the greenhouse microclimate and the ambient environment in the rainy- and dry- seasons respectively. This result aligns with the findings of Fatnassi *et al.* (2002) and Bailey *et al.* (2003), who investigated greenhouse microclimate in the tropics for the production of potato and reported a temperature range of 10 – 12 °C. This can be attributed to the capacity of the humidifier to introduce moisture into the greenhouse atmosphere thereby causing cooling by evaporation. The high temperatures recorded outside the greenhouse had negative influence on the growth and development of the potato and this eventually had effect on the quality and quantity of yield. Although high temperatures are beneficial for plant growth and yield, however, temperatures exceeding species-specific thresholds have deleterious effects on plant development and product quality, as high temperatures result to nutrient and hormone imbalances (Rouphaela *et al.*, 2018). Kacira (2004), Kacira (2012) and Rouphaela *et al.* (2018) reported that daily thermal periodicity is required for proper physiological functioning with thermal differences of between 5 and 7 °C, while Shamshiri *et al.* (2018) reported the stunted growth and development of potato in a greenhouse under a tropical condition. Kittas *et al.* (2013) reported that the maximum greenhouse air temperature of about 30 - 35°C is required for optimal tomato production, while Jones (2013) reported that air temperatures in the range 21 - 29.5°C in the day and 18.5 - 21°C in the night are optimal for greenhouse crops.

3.2 Relative Humidity

The data obtained for the dry season showed that the relative humidity ranged from 64.4 to 80.3% and 30.8% to 83.5% in and outside the greenhouse respectively, while in the rainy season relative humidity was in the range 75.6 to 91.3%, and 60.2 to 91.6% in- and out- side the greenhouse. The descriptive statistics shows that greenhouse mean RH in the rainy- and dry- seasons were 82.3±2.77 and 75.3±2.40%, while the mean RH recorded outside the greenhouse in the rainy- and dry- seasons were 78.5±7.30 and 63.1±10.37% as compared to 70 to 85% required RH for successful production of Irish potato. RH mean differences of 3.8 and 12.2% were recorded in the rainy- and dry- seasons between within the greenhouse and outside the greenhouse. The mean relative humidity outside the greenhouse in the dry season ranged from 30 and 50% in the day (between 1 to 4pm) but ranged from 65 and 76 % inside the greenhouse. The relative humidity readings outside the greenhouse in most cases were less than 75%, the minimum allowable RH for successful Irish potato production. The effect of low relative humidity on the growth and development led to increased rate of evapotranspiration, which caused a reduction in photosynthesis, leaf dehydration and subsequently stunted growth. This observation was in line with Kittas *et al.* (2005)and Shamshiri *et al.* (2018) who reported stunted and discoloured tomato when tomato was exposed to relative humidity as low as 40% throughout its growing period.

Figures 6 and 7 show the daily relative humidity fluctuations in- and out- side greenhouse in the rainy season. It can be deduced from Figures 6 and 7 that the relative humidity was consistently higher in the greenhouse than outside the greenhouse in the two experiments. Though the relative humidity recorded outside the greenhouse in the rainy season experiment was initially high, but there was a sharp drop from 86% to 65.9% on day 91. This sharp drop of the relative humidity was at the peak of the heat period of the dry season. It was observed that there were more fluctuations in the RH readings in the rainy season than in the dry season. The RH readings outside the greenhouse in the dry season were in most cases about 60%, which is considered to be very low and in some instances was as low as 30% in the peak of the heat period in dry season. This can be attributed to low evaporation of moisture into the atmosphere to cause moisture buildup. The trend of readings recorded in the dry season as shown in Figure 7 reveals that the highest value of RH recorded was 86%, while the lowest was 30%. Figures 6 and 7 show that though the readings of RH in the greenhouse fluctuated, but the fluctuations were narrow unlike outside the greenhouse where the fluctuations were wider. The greenhouse RH at some point at the peak period of the dry season was 60%, a value lower than the least recommended RH of 70% and this consequently had effect on the yield. The direct effect of high temperature and low relative humidity observed outside the greenhouse was relatively low yield in the rainy season and very poor yield in the dry season. This agrees with Wollaeger and Runkle (2017), who reported poor tomato yield of tomato when exposed to relative humidity of 40%. Katsoulas and Kittas

(2008) and Shamshiri *et al.* (2018)reported that plants exposed to high temperature require high relative humidity to neutralise heat stress that results from high temperatures.

3.3 Vapour Pressure Deficit (VPD)

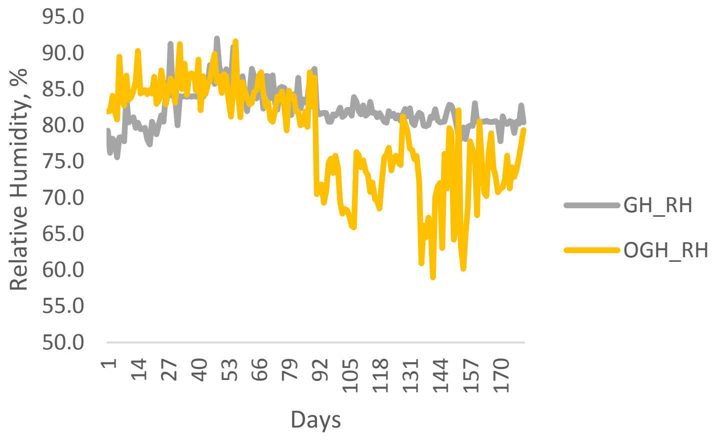
Vapour Pressure Deficit (VPD), which is an indicator of atmospheric moisture demand, fluctuated from 0.23 to 0.88 kPa and 0.59 to 1.25 kPa in the rainy- and dry- seasons, respectively, inside the greenhouse and 0.73 to 2.03 kPa and 0.42 to 4.01 kPa in the rainy- and dry- seasons, respectively, outside the greenhouse. There were considerable upward and downward trends in the greenhouse, but within the range of 0.4 to 1.0 kPa and in few occasions slightly about 1 kPa.

The mean Vapour Pressure Deficit in the rainy season was 0.52±0.10 and 1.23±0.24 kPa in- and out- side the greenhouse respectively, respectively, as compared to 0.69±0.25 and 2.21±0.66 kPa recorded in- and out- side the greenhouse respectively in the dry season. The VPD outside the greenhouse was in several instances higher than 1kPa in the dry season, which is the benchmark VPD value that favours the growth and development of Irish potato. However, in the rainy season experiment, VPD outside the greenhouse was observed to have values below 1kPa, but the frequent fluctuation of air temperature and relative humidity outside the greenhouse resulted to high VPD values whose cumulative effect did not favour potato growth and development. According to Dorais *et al.* (2004) and Wollaeger and Runkle (2017) relative humidity (RH) and VPD in greenhouses affect crop quality and high RH and low VPD could result to heat damage due to reduction in evapotranspiration rates, the primary cooling mechanism of plants, and reduces translocation of ions which eventually results in nutrient deficiency symptoms and lowers visual quality. High VPD also induces oxidative stress, which results in severe adverse effects on marketable yield (Dorais *et al.*, 2004; Rosales *et al.*, 2011; Gruda, 2013; Rouphaela *et al.*, 2018). Values of VPD in excess of 1.5 – 2.0 kPa are known to decrease the stomatal conductance of crops (Bailey, 2000; Katsoulas and Kittas, 2008).

The VPD in the greenhouse was in several cases about 1 kPa as compared to the VPD outside the greenhouse which was in several instances above 1 kPa as shown in Figures 5 and 6. It can also be observed in Figures5 and 6 that outside the greenhouse VPD fluctuated more often and the degree of fluctuation vary higher than inside the greenhouse. In most instances in the dry season in the day VPD outside the greenhouse was above the VPD range of 0.4 to

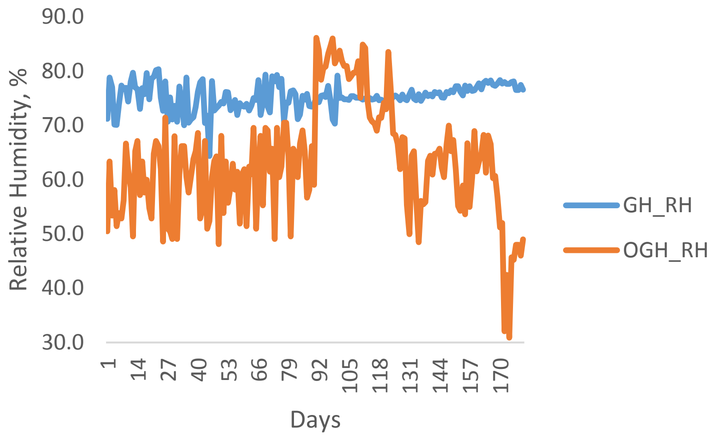
1.0 kPa obtainable in areas where the potato is cultivated. The high values of VPD outside the greenhouse both in the rainy- and dry- season was as a result of the high ambient air temperature and low relative humidity. The bandwagon effect of this scenario was high evapotranspiration which eventually resulted to poor crop growth and development, heat stress, low transfer of nutrients from the roots to other parts of the plants and consequently translated to poor yield. Speetjens *et al.* (2012) reported that VPD values between 0.5 and 0.8 kPa are optimal for most greenhouse crops and will prevent yield reduction due to fruit shrinkage and fungal diseases. Rosales *et al.* (2011) and Speetjens *et al.* (2012)reported that VPD values between 0.2 and 1.0 kPa are recommended for both pollination and prevention of fungal diseases, while Iraqi *et al.* (1995) and Katsoulas and Kittas (2008)recommended optimal day and night hours VPD of 0.8 kPa for optimal photosynthetic rate and would consequently result to optimal greenhouse crop yield.

The result of the analysis of variance showed that the p-values obtained from all the comparison of environmental data obtained in- and out- side the greenhouse at a significant level of 0.05 were less than 0.01. These values of p showed that there were significant differences between the climatic data recorded in- and out- side the greenhouse experiments.



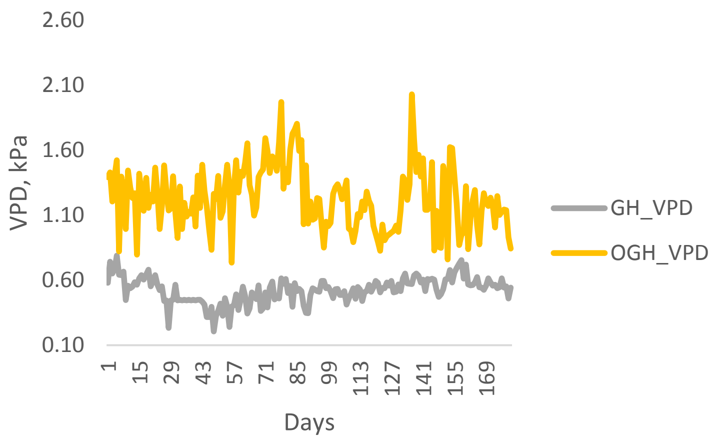
GH_RH: temperature inside the greenhouse, OGH_ RH: temperature outside the greenhouse

Figure 6: Relative Humidity Fluctuations In- and out- side Greenhouse in the Rainy Season



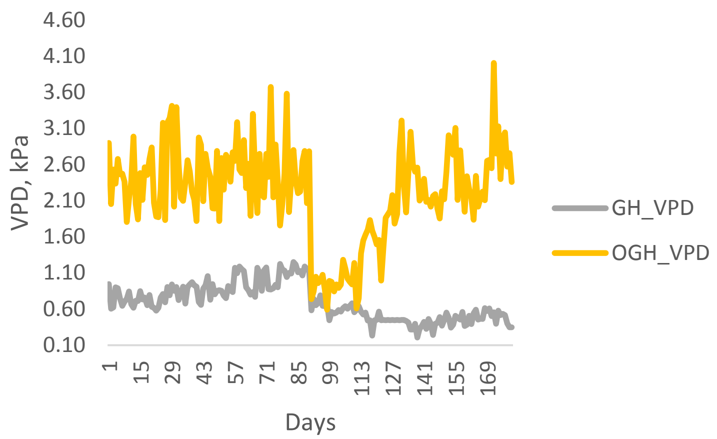
GH_RH: temperature inside the greenhouse, OGH_ RH: temperature outside the greenhouse

Figure 7: Relative Humidity Fluctuations In- and out- side Greenhouse in the Dry Season



GH_VPD: temperature inside the greenhouse; OGH_ VPD: temperature outside the greenhouse

Figure 8: VPD Fluctuations In- and out- side the Greenhouse in the Dry Season



GH_VPD: temperature inside the greenhouse; OGH_VPD: temperature outside the greenhouse

Figure 9: Vapour Pressure Deficit Fluctuations In- and out- side the Greenhouse in the Rainy Season

3.4 Irish Potato Yield

The descriptive statistics of the Irish potato yield obtained in the rainy season experiment are as presented in Table1 and shows that Nicola, Diamant, Bertita, Okonkwo and New Seed had yield mean and standard deviation of 117.55 (SD = 29.67), 173.43 (SD = 45.66), 230.54 (SD = 57.53), 218.05 (SD = 52.40) and 122.60 (SD = 26.16) in the greenhouse in the rainy season, respectively, while outside the greenhouse 39.57 (SD = 13.72), 53.65 (SD = 18.59), 53.52 (SD = 22.14), 60.75 (SD = 19.56) and 34.66 (SD = 14.06) yield means were obtained from Nicola, Diamant, Bertita, Okonkwo and New Seed respectively. The F statistics (734.96) obtained with the corresponding first degree of freedom = 9 and second degree of freedom= 1490 was greater than the F critical at $\alpha = 0.01$ (2.42) and $\alpha = 0.05$ (1.89) levels of confidence. This shows that the difference between the yield obtained in- and out- side the greenhouse was significantly different. Tukey's HSD test was carried out by pairing and comparing the means of the yield of a variety obtained in the greenhouse against its yield outside the greenhouse. The Tukey-Kramer HSD $Q_{statistic}$ was obtained based on the number of treatments (10) and degrees of freedom for the error term (1490) at the significance levels of $\alpha = 0.01$ and 0.05 in the Studendised Range Distribution Table. The Tukey-Kramer HSD $Q_{critical}$ obtained were: $Q_{critical}$ ($\alpha = 0.01$) = 5.1678 and $Q_{critical}$ ($\alpha = 0.05$) = 4.4810. The Tukey-Kramer HSD test revealed that the comparison of mean yield obtained of all the varieties were significantly different at p = 0.01.

Table 1: Descriptive Statistics of Potato Yield - Rainy season

Groups	Count	Total Yield (g)	Mean (g)	Sample Variance	Standard Deviation
GH_A	150	17631.90	117.55	880.20	29.67
GH_B	150	26014.00	173.43	2085.12	45.66
GH_C	150	34581.40	230.54	3309.39	57.53
GH_D	150	32707.50	218.05	2745.50	52.40
GH_E	150	18389.40	122.60	684.18	26.16
OGH_A	150	5935.77	39.57	188.22	13.72
OGH_B	150	8048.22	53.65	345.59	18.59
OGH_C	150	8028.29	53.52	490.00	22.14
OGH_D	150	9111.84	60.75	382.51	19.56
OGH_E	150	5199.57	34.66	197.75	14.06

GH = Greenhouse, OGH = Outside the greenhouse, A= Nicola, B = Bertita, C = Diamant, D = Okonkwo, E = New Seed

The descriptive statistics of dry season Irish potato yield is presented in Table 5. The descriptive statistics in Table 2 shows that the total yield from all the varieties in the greenhouse ranged from 16.544 to 29.082 kg, while outside the greenhouse the yield ranged from 0.412 to 0.621 g. Nicola, Diamant, Bertita, Okonkwo and New seed had yield mean and standard deviation of 110.30 (SD = 28.55), 154.02 (SD = 28.94), 192.36 (SD = 49.18), 193.88 (SD = 41.52) and 117.74 (SD = 34.62), and 2.77 (SD = 2.45), 3.03 (SD = 2.27), 3.73 (SD = 2.69), 4.14 (SD = 3.19) and 2.75 (SD = 2.20) in- and out- side the greenhouse respectively. Okonkwo and New seed had yields of 621 and 412 g, the highest and least recorded yield outside the greenhouse in the dry season.

The ANOVA at 9 and 1490 degrees of freedom shows that the yield in- and out- side the greenhouse in the dry season experiment was also significantly different at both 0.01 and 0.05 levels of significance with F critical values of 2.42 and 1.89, respectively. The levels of significance from the comparison of yield using ANOVA strongly suggested the use of a post-hoc test in order to establish the variety pair that differed significantly. As a result, the yield was further subjected to Tukey's HSD test. The result of the Tukey's HSD test on the comparison of the mean of the yield from the five varieties obtained in- and out- side the greenhouse. The post-hoc test showed that the Tukey-Kramer HSD Q critical at 0.01 and 0.05 levels of significance (k= 10, degree of freedom = 1490) were 5.1678 and 4. 4.4810, respectively. The Table also reveals that the Tukey's HSD Q statistics of all the pairs compared were greater than the Tukey-Kramer HSD Q critical values and this shows that the pair-comparisons were significantly different at both p = 0.01 and p = 0.05 levels of significance.

It was observed in all the experiments that Nicola and New Seed had the least yield in- and out- side the greenhouse. The differences within and between the yield of the varieties could be attributed to individual and variety differences. The topographical effect could also have had effect on the yield, as the elevation of Irish potato producing areas in Nigeria ranges between 1200 to 1800 m above mean sea level, whereas the elevation of Ilorin is only about 304 m above the mean sea level.

Table 2: Descriptive Statistics of Potato Yield in the Dry Season

Groups	Count	Total Yield (g)	Mean (g)	Sample Variance	Standard Deviation
GH_A	150	16544.30	110.30	815.26	28.55
GH_B	150	23102.30	154.02	837.40	28.94
GH_C	150	28554.10	190.36	2418.43	49.18
GH_D	150	29082.00	193.88	1723.90	41.52
GH_E	150	17661.20	117.74	1198.26	34.62

OGH_A	150	416.03	2.77	6.00	2.45
OGH_B	150	454.47	3.03	5.13	2.27
OGH_C	150	558.95	3.73	7.24	2.69
OGH_D	150	621.32	4.14	10.17	3.19
OGH_E	150	412.14	2.75	4.86	2.20

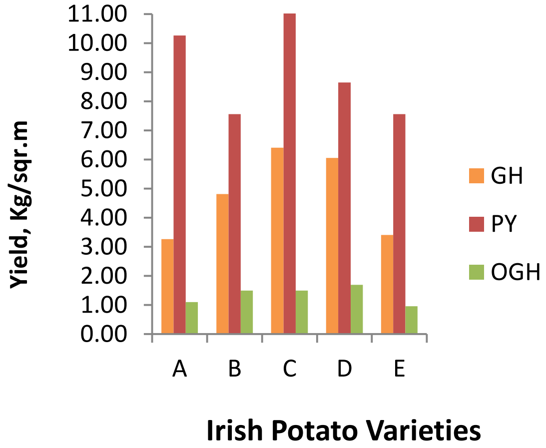
GH – greenhouse, OGH = outside the greenhouse
A = Nicola, B = Diamant, C = Bertita, D = Okonkwo, E = New Seed

Presented in Figures 10 and 11 are the charts showing the yield in grams per square metre (kg/m^2) obtained in the rainy- and dry- season experiments respectively. The yield obtained from Nicola, Diamant, Bertita, Okonkwo and New Seed were 3.26, 4.82, 6.40, 6.06 and 3.41 kg/m^2 and 1.10, 1.49, 1.49, 1.69 and 0.96 kg/m^2in- and out- side the greenhouse in the rainy season.

The yield obtained in the dry season experiment in Figure 11 shows that Nicola, Diamant, Bertita, Okonkwo and New Seed yielded 3.06, 4.28, 5.29, 5.38 and 3.27 kg/m^2, and 0.77, 0.08, 0.10, 0.12 and 0.076 kg/m^2 in- and out- side the greenhouse respectively. Averagely, the equivalent yield obtained in Plateau State, the home of Irish potato, from these common varieties, Nicola, Bertita, Okonkwo, Diamant and New Seed were 10.26, 7.56, 11.34, 8.64 and 7.56 kg/m^2 respectively.

It can be observed from Figures 10 and 8 that Diamant, Bertita and Okonkwo consistently had the highest yield in all the experiments, while Nicola and New seed had the least yield in the experiments. The yield obtained in the rainy season experiment was higher than that obtained in the dry season experiment as the upward frequent fluctuation of greenhouse temperature in the dry season had effect on the quality and quantity of greenhouse yield.

The descriptive statistics of yield in Plateau State and yield in the greenhouse reveal that the sum, mean, variance and standard deviation of yield in Plateau State were 45.36, 9.07, 2.83 and 1.68. The analysis of variance of the yield obtained from Plateau State significantly differed from the yield obtained inside the greenhouse in the rainy- and dry- seasons with F-statistics, p-value and F-critical values of 18.56, $p<0.01$ and 11.26, and 35.54, $p<0.01$ and 11.26 respectively in the rainy- and dry- season. The percentage difference in yield obtained in Plateau State and the greenhouse for Nicola, Diamant, Bertita, Okonkwo and New Seed were 68.19, 36.30, 43.54, 29.90 and 54.96%, and 70.18, 43.39, 53.35, 72.45 and 56.75% in the rainy- and dry- season, respectively. This shows that the greenhouse performed averagely to some extent and the differences in the yield can be attributed to management techniques, location and variation within varieties.



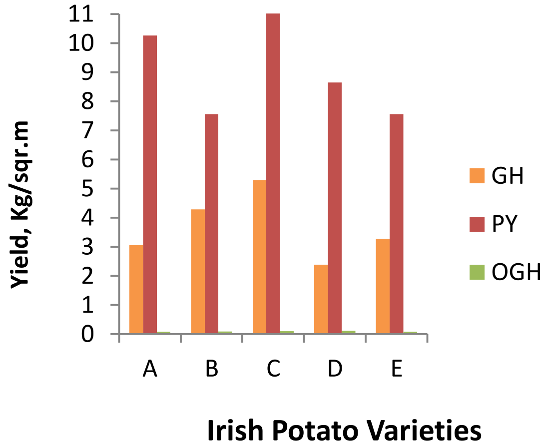


Figure10: Yield of Potato in Plateau, Greenhouse and Outside the Outside the Greenhousein the Rainy Season

Figure**11:** Yield of Potato in Plateau, Greenhouse and Greenhouse in the Dry Season

GH = Greenhouse, OGH = Outside the greenhouse, PY = Plateau yield; A = Nicola, B = Diamant, C = Bertita, D = Okonkwo, E = New Seed

3.5 Response Of Irish Potato Yield To Temperature, Relative Humidity And Vapour Pressure Deficit

The effect of temperature, relative humidity, and vapour pressure deficit on potato yield in- and out- side the greenhouse was established using linear, log-linear and log-log regression model analysis. The analysis of variance showed that temperature, relative humidity, and vapour pressure deficit had significant effect on the yield obtained from Nicola ($p < 0.01$), Diamant ($p = 0.02$), Bertita ($p < 0.01$), Okonkwo ($p < 0.01$) and New seed ($p < 0.01$) at 1% level of significance inside the greenhouse, and Nicola ($p = 0.02$) at 10% level of significance, and Bertita ($p < 0.01$) and New seed ($p < 0.01$) at 1% level of significance outside the greenhouse in the rainy season experiment. In the dry season experiment, temperature, relative humidity, and vapour pressure had significant effect on the yield obtained from Nicola ($p < 0.01$) and Okonkwo ($p < 0.01$) inside the greenhouse, while outside the greenhouse the effect of temperature, relative humidity, and vapour pressure deficit on the yield from all the varieties was statistically significant.

The appropriate model for each of the varieties of Irish potato was chosen based on the significant level of the model (best-fitted model), the significance level of the environmental parameters and the coefficient of determination (R^2).

Linear-log regression analysis was used to establish the relationship between the air temperature, relative humidity and vapour pressure deficit, and the potato yield. It showed that air temperature, relative humidity and vapour pressure deficit had statistically significant effect (@10%)on air temperature and vapour pressure deficit on the yield of Nicola level of significance and had an inverse and direct relationship with the yield of Nicola with coefficients of regression of -132.12 and 72.07 for air temperature and vapour pressure deficit respectively in the rainy season, while relative humidity had a direct relationship with yield but statistically insignificant (p = 0.28) with a coefficient of regression of 230.78. The regression analysis showed that the P value (Prob>F = 0.0003) for the regression as a whole for the combined effect of air temperature, relative humidity, and vapour pressure deficit statistically significantly predicted yield obtained from Nicola. A coefficient of determination (R^2) of 0.28 was obtained, and this value indicates that the response model can explain 28% of the total variability in the responses for Nicola to air temperature, relative humidity and vapour pressure deficit. The regression equation is shown in equation 1.

$$Y_{Nicola} = -522.37679 - 132.12^{*}\ln T + 230.7830\ln RH + 72.07^{*}\ln VPD \quad (R^2 = 0.28) \qquad 1$$

The log-log regression analysis was chosen to predict the yield of Diamant from air temperature, relative humidity, and vapour pressure deficit and it showed that all parameters were statistically significant. The air temperature had an inverse relationship with yield, while relative humidity and vapour pressure deficit had direct relationship with yield with -9.36, 31.74 and 7.42 coefficients of regression respectively. The Model had a significant F-value of 6.13 and Prob > F value of 0.0011, which is less than 0.05 indicating that the model terms are significant. A coefficient of determination (R^2) of 0.25 was obtained, and this value indicates that the response model can explain 25% of the total variability in the responses of Diamant *to air temperature, relative humidity and vapour pressure deficit*. Though the coefficient of determination is low, however, the overall p-value (p = 0.0011) of all the independent variables is statistically significant. equation 2 is the model equation for Diamant.

$$\ln Y_{\mathrm{Diamant}} = -101.74^{**} - 9.36^{**}\ln T + 31.74^{**}\ln RH + 7.42^{***}\ln VPD \quad (R^2 = 0.25) \qquad 2$$

A linear regression model was chosen for Bertita as it was the best model with the highest R^2 and had all the independent variables significant. The relationship of T with yield was directly and statistically significant at 1% level of significance with a regression coefficient of 2.929, while RH and VPD were inversely and statistically significant at 1% level of significance with coefficients of -0.62 and -23.65 respectively as shown in equation 3. The Model had a significant F-value of 20.44 and Prob > F value of 0.0000 ($p<0.05$) and a coefficient of determination (R^2) of 0.52. The high coefficient of determination showed excellent correlations between the independent variables and this value indicates that the response model can explain 52% of the total variability in the responses of Bertita to the environmental factors.

$$Y_{Batita} = 21.662 + 2.929^{*}T - 0.617^{*}RH - 23.651^{*}VPD \quad (R^2 = 0.52) \qquad 3$$

A log-log regression model was chosen in the case of the Okonkwo variety. A directly and statistically significant relationship was observed between air temperature and yield of Okonkwo, while an inversely and statistically significant relationship was observed between RH and yield, and VPD and yield. The coefficients of regression were -471.96, 1037.58 and 275.24 for T, RH and VPD respectively. Shown in equation 4 is the regression equation that can be used to predict the yield from Okonkwo variety of Irish potato. The model has a significant F-value of 6.01 and Prob > F value of 0.0013 ($p<0.05$) and a coefficient of determination (R^2) of 0.24. Though the coefficient of determination is low, however, the overall p-value ($p = 0.0013$) of all the independent variables is statistically significant.

$$\ln Y_{\mathrm{Okon}kwo} = -2844 - 471.96^{**}\ln T + 1037.58^{*}\ln RH - 275.24^{**}\ln VPD \quad (R^2 = 0.24) \qquad 4$$

A log-linear model was chosen for New Seed as shown in equation 5. The analysis revealed that the air temperature was directly and statistically insignificant to yield with a regression coefficient of 0.01, while relative humidity and vapour pressure deficit were inversely and statistically significant to yield at 1% significant level with coefficients of regression of -0.04 and -0.58 respectively. This model had a significant F-value of 38.38 and Prob > F value of 0.0000 ($p<0.05$) and a coefficient of determination (R^2) of 0.67. The high coefficient of determination showed excellent correlations between the independent variables and this value indicates that the response model can explain 67% of the total variability in the responses of Bertita to temperature, relative humidity and vapour pressure deficit.

$$\ln Y_{\text{New seed}} = 6.50^{***} + 0.01T - 0.04^{***}RH - 0.58^{***}VPD \, (R^2 = 0.67) \qquad 5$$

The low values of R^2 in some of the regression analysis can be explained to be the multicollinearity of the independent variables, a condition whereby highly correlated independent variables (T, RH and VPD) are such that their explanatory power and the significance of their coefficients is divided up between the independent variables themselves and the dependent variables.

The positive coefficients in the equation represent a direct relationship between the environmental parameters and yield, while the negative coefficients represent an inverse relationship between them. A unit increment in any of the positive coefficients of temperature, relative humidity and vapour pressure deficit, would result to an increment in yield by the coefficient of regression of temperature, relative humidity and vapour pressure deficit, while a negative coefficient would result in a decrement in yield in the magnitude of the regression coefficient of T, RH and VPD obtained. However, the increment in air temperature, relative humidity, and vapour pressure deficit beyond the threshold range of 18 to 35^{o}C, 70 to 85% and 0.4 to 1.0 kPa would instead result to decrease in yield vice versa. It was observed that air temperature, relative humidity, and vapour pressure deficit all had a direct relationship with potato yield within the threshold limits. Also, it was found that vapour pressure deficit is the most critical factor affecting potato yield. This conforms with the findings of Dorais *et al.* (2001) and Dorais *et al.* (2004) on greenhouse tomato, Bakker (2009) on sweet pepper, Wijnands (2003)on cucumbers, Gautier *et al.* (2001) andShamshiri *et al.* (2018) on tomato. They all reported that high VPD reduces the growth and development of tomato, sweet pepper, cucumber and potato and also reduces the water content, dry matter content and sugar content of vegetables and fruits.

The analysis of variance of the air temperature, relative humidity and vapour pressure deficit showed that that the P value (observation = 60, df1 = 3, df2 = 56) for the combined effect of air temperature, relative humidity and VPD significantly influenced the yield obtained from Nicola, $F(3,56) = 6.17$, $p < 0.01$, $R^2 = 0.25$, Diamant, $F(3,56) = 3.82$, $p = 0.01$, $R^2 = 0.17$, Bertita, $F(3,56) = 5.46$, $p<0.01$, $R^2 = 0.23$, Okonkwo, $F(3,56) = 4.29$, $p<0.01$, $R^2 = 0.19$ and New seed, $F(3,56) = 7.08$, $p<0.01$, $R^2 = 0.28$ inside the greenhouse in the rainy season, while Bertita, $F(3,56) = 20.44$, $p<0.01$, $R^2 = 0.52$ and New seed $F(3,56) = 36.16$, $p<0.01$, $R^2 = 0.66$ were significantly affected outside the greenhouse at the significant level of 0.05. The combined effect of T, RH and VPD, however, significantly had effected on yield obtained from Nicola, $F(3,56) = 5.42$, $p<0.01$, $R^2 = 0.23$ and Okonkwo, $F(3,56) = 4.77$, $p<0.01$, $R^2 = 0.20$ inside the greenhouse, while outside the greenhouse in the dry season Nicola $F(3,56) = 7.00$, $p<0.01$, $R^2 = 0.27$, Diamant $F(3,56) = 8.51$, $p<0.01$, $R^2 = 0.31$, Bertita $F(3,56) = 8.99$, $p<0.01$, $R^2 = 0.33$, Okonkwo $F(3,56) = 5.77$, $p<0.01$, $R^2 = 0.24$ and New seed $F(3,56) = 10.20$, $p<0.01$, $R^2 = 0.35$ were significantly affected by temperature, relative humidity and vapour pressure deficit at the significant level of 0.05. These results suggest that the yield to some extent can be explained by the T, RH, and VPD despite the low R^2 values obtained. A low R^2 does not negate the importance of any significant variables as statistically significant p-values continue to identify relationships and the coefficients have the same interpretation(Neter *et al.*, 1990; Neter and Wasserman, 2004). In this context, T, RH, and VPD had significant effect on all the varieties.

4.0 CONCLUSIONS

The feasibility of the appropriateness of a split-gable greenhouse in the tropical climate for the production of Irish potato was investigated. The major indices for the evaluation were the regulation of the greenhouse microclimate to suit Irish potato production. The following conclusions can be drawn:

- i The variation observed between the environmental parameters in- and out- side the greenhouse established independence of the greenhouse climate from the ambient
- ii A significant yield difference was obtained between the yield in- and out- side the greenhouse
- iii Greenhouse yield obtained showed that with proper management techniques the crop can be profitably cultivated under the greenhouse in the tropical conditions.
- iv Diamant (B), Batista (C) and Okonkwo (D) varieties of the potato showed good potential of being produced in a greenhouse in the tropics.

5.0 RECOMMENDATIONS

The following recommendations can made (i) other glazing materials should be tested and (ii) more varieties of the potato should be tested in order to increase the number of viable varieties that can be cultivated in the tropics

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