COMPARATIVE EVALUATION OF PERFORMANCE OF COMMERCIAL GREENHOUSES IN COASTAL HUMID CLIMATIC REGION OF KENYA

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Abstract

Appropriate production structures are essential in promoting growth and yield of crops under protected cultivation. The need to access food all year round by the ever increasing world population demands that technologies such as greenhouse production be engaged widely in food production efforts by all producers. This technology can be employed in both temperate and tropical climates. Identification of a greenhouse design that will maximize on the most limiting climatic factors in order to produce a conducive micro-climate that stimulates growth is an important step in the decision to use greenhouse farming. To recommend the best commercial greenhouse for hot humid coastal climatic region of Kenya, a comparative study was conducted in Mtwapa for two seasons in 2017. The study compared growth and yield of tomato var. ANNA F1 in Amiran and horti-pro greenhouse prototypes. All agronomic and nutritional factors were held constant for the two greenhouses and compared against a crop grown in the open field. Amiran greenhouse promoted significantly (p = 0.001) longer plant vines, but produced lower fruit yield compared to Horti-pro greenhouse. The Amiran tomatoes however had significantly (p = 0.05) sweeter fruits than those in Horti-pro. The temperature-relative humidity combination in the Amiran greenhouse was cooler but more humid than that from Horti-pro. There were no significant differences in micro-climate, growth and yield of tomatoes between the two greenhouses and those grown in the open field during the long rains. It was however much cheaper by 30% to install Horti-pro greenhouse compared to Amiran models. To enhance the productivity of greenhouses, investment in automation of micro-climate control systems is essential as well as targeting off-season production to maximize greenhouse economic benefits. Farmers in the hot humid coast may consider using UV coated PVC 205 micron cover material to reduce the cost of production as well as maximize yields.

Key Words: Greenhouse performance, Hot-humid climate, Amiran, Horti-pro, Anna F1

Introduction

Greenhouse technology is among the modern agricultural production technologies that maybe a major contributor towards attaining an all-year-round crop production (FAO, 2013). The technology has been applied in both temperate and tropical climate with a lot of success (FAO (2013). In the developed countries, this technology has been automated and is operated under controlled and more efficient systems. The scale of greenhouse production in temperate climate is higher than that in the tropical climate of Africa (Rajack (2013) and FAO, (2013). Morgan (2017) observed that the success of any greenhouse is dependent on proper identification and overcoming of the most limiting climatic problem in a particular area and obtaining the maximum growth rates possible from a crop. The most limiting factor in tropical greenhouses is the temperature-humidity combinations (Ramin, 2007) and Morgan, 2017). A greenhouse design that works well in a cool climate will not be the best design for a humid-tropical climate (Morgan, 2017).

Different greenhouses are characterized by the level of protection from the outside environment they can offer and the capability they can provide growers to control the inside environment to a specific set of conditions (Hartley, 2018). Tropical areas experience hot conditions for much of the year. In lowland areas, the humidity can be extreme and light levels can fluctuate from high on bright sunny days to rather low under overcast conditions, particularly during the rainy season which reduces the light levels available for crop growth. Insect pressure in tropical climates is often very high. This requires the use of insect mesh over vents and on any open-sided part of production structures. Good tropical greenhouse designs therefore, can be as simple as a rain cover or plastic roof with open or roll-up sides covered with insect mesh.

In Kenya, greenhouses were established in the mid-1980s in the Kenya highlands. The greenhouse technology though at very low adoption levels in the Coastal humid region of Kenya has been in the region for the last 10 years (Sanzua et al., 2018). Amiran Kenya has installed more greenhouses in the coastal counties than any other commercial greenhouse company. Horti-pro comes in a distant second with greenhouses installed only in Kilifi County (Sanzua et al., 2018). The installed greenhouses have performed sub-optimally at an average of 10% compared to the optimum. This has contributed to the myth that greenhouses cannot perform well in the hot humid coastal regions of this country (Sanzua et al., 2014)

To recommend the best material for development of a suitable affordable greenhouse design for the hot humid coastal region of Kenya, a comparative study was conducted using the most common commercial greenhouses in the region. Two common designs of commercial greenhouses were evaluated under coastal humid conditions for two seasons. Model prototypes of Amiran and Horti-pro greenhouses were designed, constructed and tested for performance using a tomato crop under coastal humid climate. The objective was to characterize the micro-climatic parameters of temperatures and humidity in the model greenhouses, evaluate the growth and yield of tomatoes grown in the model greenhouses and undertake a cost-benefit analysis of growing a tomato crop in the two model greenhouses in the coastal humid agro-ecological zones of Kenya.

Methodology

An experiment to compare performance of two most common commercial greenhouses in the hot humid coastal region of Kenya was established at Mtwapa, 18 km North of Mombasa County in Kenya. The site was located at a Latitude of 3˚ 56' S; Longitude 39˚ 44' E and at an altitude of 25m ASL. The experiment was conducted in 2017. Four prototypes of greenhouse measuring 5m x 4m x 5m were constructed using solarig® cover and 17 mesh size in the design of Amiran greenhouse. Similarly, four greenhouse prototypes measuring 5m x 4m x 5m in the design of Horti-pro greenhouses were constructed using UV treated polythene cover of 205 microns and mesh size of 50. The treatments were laid out in a randomized complete block design and tested against a control plot in the open field which was also replicated four times. Performance of the three treatments was measured using ANNA F1 tomato variety as a test crop. One seedling was planted into each pot filled with solarized forest soil and farm yard manure mixture of 1:1 ratio. The mixture was drenched with insecticide to kill soil pests. The experiment was carried out in two repeat trials. Each trial used a fresh mixture of the potting medium in sterilized pots.

Before planting, the tomato seedlings were raised in trays using sterile media for three (3) weeks then transplanted into 10 kg capacity sized pots. Planting was done with 10g of Diammonium Phosphate (DAP) basal fertilizer per pot and set under drip irrigation. Each greenhouse was planted with twenty (20) potted tomato seedlings. The pots were spaced at 90 cm x 100 cm with a margin of 0.5 m from the edges of each green house. The crop was top dressed with Calcium Ammonium Nitrate (CAN) 28 days after transplanting (DAT), and supplemented with Calcium and Magnesium foliar feed fortnightly. Data was collected from 10 plants in the middle rows of the greenhouses. Plant height was measured every 7 days using a meter rule and a thread, the measurements were given in centimeters. Observation was made to record the date to first flower in each greenhouse prototype, the number of fruit clusters per plant and the number of fruits per each fruit cluster was determined every week. During the harvesting season, fruits were harvested and weighed using an electronic weighing balance and results recorded in grams (g). Four fruits were selected randomly from the ripe fruits in each greenhouse prototype and measured to determine fruit size using a veneer calipers. The ripe fruits were taken to the laboratory to determine total soluble solids (TSS) and total titratable acidity (TTA). Percent total soluble solids were measured by dropping an aliquot of tomato juice on the prism of Abe refractometer and results were read. Total titratable acidity was measured by diluting an aliquot of tomato juice to 1% and titrating it with 0.1N NaOH. Total titratable acidity was calculated using the formula; % TTA= 0.064 x Titre value (mls) x dilution factor. The temperature and relative humidity in each of the treatments were monitored throughout the growing season and data was recorded. Harvested fruits were tested for their keeping quality at room temperature. Four (4) ripe tomato fruits at color break were selected from each greenhouse and stored under room temperature. The fruits were observed for changes in the days taken for fruits to turn from pink hard, red hard, red tending to soft, red soft and finally rotting point. The time it took in days for the first fruit to rot in each greenhouse was used to establish the shelf life of the test tomato set.

Data analysis

All data was analyzed using Statistical Analysis System (SAS) software. Means were subjected to LSD test at 5% probability level.

Results

The soil media used had the below characteristics (Table 1).

Microclimatic conditions

Results showed that temperatures in the open field were significantly lower than those in the Amiran and Horti-pro treatments in both seasons. Relative humidity was generally lower in the open field treatments compared to conditions in Amiran and Horti-pro respectively but the difference was not significant at p = 0.05 significance level. Horti-pro maintained comparatively higher RH over the two seasons (Table 2).

Height of tomato plants was significantly different between the two seasons. The height of tomato plants grown in Amiran and that of tomatoes grown in Horti-pro prototypes were not significantly different in the first season at P=0.05. Plants grown in the open field were significantly shorter than those grown under Horti-pro and Amiran greenhouse types at p=0.05 in both seasons (Table 3). Season had significant influence on tomato plant height in both greenhouses (Table 4).

Table 1: Characteristics of the soil media

Parameter	Conditions
Type of soil	Pleistocene lagoon sands & clay
Vegetation type	Mixed forest
PH H20	6.7
PH CaCl2	5.9
EC (SM/CM	0.043
% C	0.66
%N	0.06
SOM	1.15
P ppm	2.72
Kppm	49.25
Ca ppm	694.45
Mg ppm	217.86
M%	1.44
BD	1.34
Soil color	grey
Texture	sand

Source: KEFRI, 2016

Table: 2. Comparative Temperature (T) and Relative Humidity (RH) recorded in Horti-pro and Amiran greenhouses prototypes across two planting seasons

Treatment	Season 1 (October-December)		Season 2 (April-July)	
	Ave -Temp °C	Ave - R H (%)	Ave -Temp °C	Ave-RH (%)
Open field	31.24b	55.47a	31.63b	59.33a
Amiran	37.88a	56.24a	34.90a	59.90a
Hort-pro	37.14a	57.38a	34.82a	60.94a

Values are means for each parameter taken weekly for 10 weeks after transplanting
[a]Means followed by same letters within columns are not significantly different at p = 0.05. n = 10.

Table 3: Effect of type of growing structure on tomato plant height

Green house type	Plant height (cm) season 1	Plant height (cm) season 2
Amiran	66.6a	126.8a
Hortipro	60.7a	97.9b
Open	52.1b	97.1b

[a]Means followed by same letters within columns are not significantly different at p = 0.05. n = 220.

Table 4: ANOVA table of tomato plant height grown under different greenhouse design structures prototypes

Source	DF	SS	Mean Square	F Value	Pr > F
Greenhouse	2	134949.92	67474.96	31.19	<.0001
Season	1	590068.77	590068.77	272.76	<.0001
Greenhouse*season	2	33310.58	16655.29	7.70	0.0005

It was observed that the weight of fruits grown in Amiran and that of fruits grown in Horti-pro greenhouses was not significantly different at p=0.05 (Table 5). The study however established significant differences in the weight of fruits produced between the two seasons at the same level of significance (Table 6). The weight of fruits significantly differed in the two seasons of study at p=0.05. The average weight of tomato fruits grown in Horti-pro greenhouse prototype was not significantly different from those grown in the open Field in both seasons at p=0.05.

The type of commercial greenhouse did not affect the size of tomato fruit. Average Fruit size was not significantly different between tomatoes produced in Amiran and Horti-pro greenhouses at p=0.05. However, fruits from open fields tended to be significantly smaller than those produced in Amiran and Hortipro greenhouse prototypes at p=0.05. Generally the results indicated that the yield and its component factors are not differently affected by the design of the common commercial greenhouses being used in the hot humid coastal Kenya (Table 8).

The number of fruit clusters borne on Horti-pro and Amiran grown tomatoes were not significantly different but the two greenhouses supported more fruit clustering than open field tomatoes at p=0.05. Horti-pro supported more clusters with more fruits than Open field conditions at (p = 0.05) but there was no significant difference in the number of fruits borne per cluster between Amiran and Horti-pro grown greenhouses at the same significance level.

The results also showed that Total titratable acidity test was not significant between treatments and across seasons, however, there was significant difference in the total soluble solids between treatments with tomatoes grown in Amiran exhibiting more sweetness than Horti-pro and open field grown tomatoes at P=0.05 (Table 9).

Regarding tomato shelf life, tomato fruits took between 26 days and 33 days from harvest to complete rot. By the 26th day, tomatoes from open field had started rotting. Those from Amiran rot at 33 days after harvesting. Fruits produced under Horti-pro treatment took 2 days less to rot than those from Amiran greenhouse (Table 10 and 11. Green house construction is fairly costly but the expected returns usually outweigh the input cost. However, in this study the cost benefit analysis indicate that it was 30% cheaper to use Horti-pro greenhouse cover material than that of Amiran.

Table 5: Average Fruit weight (g) of tomatoes grown in two different commercial greenhouse prototypes in the hot humid coastal Kenya

Type of greenhouse prototype	**Average Tomato fruit weight (g)**
Open field	715a
Amiran	806a
Hortipro	841.4a

[a]Means followed by same letters within columns are not significantly different at p = 0.05. n = 40.

Table 6: Mean Weight of Tomato fruits grown in different seasons in the hot humid coastal Kenya

Season	Average Fruit weight of tomato (g)
1	994a
2	581b

[a]Means followed by same letters within columns are not significantly different at p = 0.05. n = 60.

Table 7: Effect of type of greenhouse design on average fruit weight (g) of tomato grown in different seasons in the hot humid coastal Kenya

Type of greenhouse	Tomato fruit weight, season 1 (g)	Tomato fruit weight, season 2 (g)
Open field (Control)	77.01b	121.06a
Amiran	115.74a	114.71b
Hort-pro	97.85b	136.95a

[a]Means followed by same letters within columns are not significantly different at p = 0.05. n = 40.

Table 8: Effect of design of greenhouse on tomato fruit yield parameters under hot humid climate

Design of greenhouse	Average tomato fruit size (cm)	Average fruit weight (g)	Average No. of fruit clusters per tomato plant	Average No. of fruits per fruit cluster
Hortipro	4.51a	841.4a	4.65a	3.73a
Amiran	4.49a	806a	4.20a	3.55ab
Open field	4.35b	715a	3.57b	3.15b

[a]Means followed by same letters within columns are not significantly different at p = 0.05

Table 9: Effect of type of greenhouse design on total acidity and Brix levels of tomatoes grown under hot humid climate of coastal Kenya

Type of greenhouse	% brix	Total titratable acidity (TTA)
Amiran	5.4a	0.38a
Hortipro	4.6b	0.34a
Open field	4.3b	0.32a

[a]Means followed by same letters within columns are not significantly different at p = 0.05, n= 12

Table. 10: Trend of deterioration of tomato fruits harvested from different types of commercial greenhouses in humid Coastal Kenya

	Treatment/Days taken to reach change stage		
Ripening Stage	Amiran	Hortipro	Open Field
Pink Hard	1.52	1.91	2.04
Red Hard	15.65	14.55	15.05
Red Tending To Soft	27.87	26.58	20.51
Red Soft	29.21	25.43	24.03
Rot	33.00	31.00	26.00

Table 11: Shelf life of Tomato fruits grown in different greenhouse designs

Type of greenhouse	**Longevity on the shelf**
Amiran	4.17a
Horti-pro	4.01b
Open field	3.13c

[a]Means followed by same letters within columns are not significantly different at p = 0.05, n= 852

Table 12: Cost Benefit Ratio of commercial greenhouse prototypes in the coast humid Kenya

Treatment	**Related total costs of production (TC)**	**Total revenue (TR)**	**Profit margin**	**Benefit/ Costs ratio (TR/TC)**
Horti-pro	45,472.00	90,265.00	44,493.00	2:01
Amiran	43,142.00	66,003.00	22,861.00	1.50
Open	24,207.00	49,080.00	24,873.00	2:01

Discussion

Tomato plants grown in Amiran greenhouses were taller but did not give more yield compared to those grown in Horti-pro greenhouses. On the Other hand, plants grown in Horti-pro greenhouses were relatively shorter but gave, more fruit clusters with larger fruits and weight and ultimately higher yields. Amiran greenhouse created fairly lower temperature-humidity combinations. Pic Plast (2018) observed that mechanical light diffusion properties in Solarig reduce burning and self-shading while improving photosynthetic efficiency. This was observed in the vigorous vegetative growth observed in plants in Amiran compared to those in Horti-pro greenhouses and open field. This was likely to have had a reducing effect on the number of fruits borne per plant. Adams et al. (2001) corroborates this when he deduced that flower numbers and poor fruit set at low temperatures as low as 28^{o}C resulted in low fruit yield. Pidwirny (2006) adds that insulation is directly related to greenhouse air temperatures. This confirms the inherent designed heat-reducing properties of solarig cover by Pic plast (2018). Lower temperatures promote plant length (Hortinews, 2013). Although the experiment showed lack of statistical significance in yield and yield components differences of the two greenhouses under comparison, Horti-pro greenhouse tended to exhibit consistently higher performance in all yield parameters. The Amiran yield could have been lower partly because of the huge mesh size which could have allowed external abiotic factors to interfere with productivity. In addition, during the fruiting stage, the higher temperatures in Horti-pro greenhouse is thought to have contributed to enhanced enzyme activity which promoted photosynthesis which directed photosynthates to the reproductive sinks as reported in a related study by Adams et.al, (2001). Worthington (2018) corroborates this and adds that a rise of even 10^{o}C can increase enzyme activity by between 50-100 %. The performance of tomato crop during the first season in all treatments did well because there was experienced high rainfall that contributed towards cooling the temperatures in all treatments and maintained high humidity almost equivalent to open field conditions.

The total soluble solids in Amiran grown tomatoes was higher than that of tomatoes grown in horti-pro and open field. The TSS is known to be influenced by temperature to promote metabolism during ripening (Kleinhenz and Natalie, 2019). The results indicated that Amiran took much longer to rot and possibly the not so rapid deterioration contributed to increased concentration of sugars over time. Similarly the process of sugar accumulation could have started in the greenhouse where the cooler temperatures in Amiran greenhouse reduced TTA while promoted the increase of TSS. The cost benefit analysis test favoured Horti-pro to Amiran greenhouse, this is despite the fact that all yield parameters and micro-climatic conditions of the two greenhouses indicated lack of significant difference. The only difference arose in the cost of raw material which indicate Horti-pro greenhouse was cheaper to construct than Amiran Solarig material cladded greenhouse.

Conclusion

The essence of greenhouse production is to promote quality and allow all year round production. Size and weight of fruit are among the quality attributes that customers look for. The same parameters are considered favorable to the farmer because they cumulatively contribute to total yield of the tomato crop. Since under the conditions of the experiment, there were no statistical differences in performance of the two greenhouses except in the cost, it can be deduced that on the basis of affordability and profitability, the Horti-pro model be used to design suitable and affordable greenhouse prototypes for coastal humid climatic zone of Kenya. The experiment indicts that the performance of greenhouse must be evaluated not only on the internal biotic and abiotic factors but external factors too.

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Conflict of interest

The authors declare no conflicting interests

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