The environment in Ghanaian greenhouses

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Report WPR-928

WAGENINGEN UNIVERSITY & RESEARCH

Fresh GREEN GHANA

NWO Netherlands Organisation for Scientific Research

Referaat
Het project "*Safe and accessible greenhouse production of (fruit) vegetables in Ghana*" ("*Fresh Green Ghana"*) wil onder anderen bijdragen aan de verbetering en verbreding van de beschermde tuinbouw door in samenwerking met tuinders gegevens te delen en technologie te verbeteren, inclusief de na-oogst keten. Dit kan bijdragen aan een grotere beschikbaarheid van verse (vrucht)groenten voor de arme stedelijke bevolking in Ghana. Gegevens van groeiomstandigheden binnen en buiten vier kassen in zuidelijk Ghana werden van januari 2018 tot en met augustus 2019 verzameld. De belangrijkste milieueigenschap is temperatuur. De temperatuur van de buitenlucht varieert tussen 21 en 35°C, en de binnentemperatuur kan tot 10°C hoger liggen. Zulke hoge temperaturen werken negatief op groei en productie van het gewas. De kastemperatuur wordt beïnvloed door hoogte, kasformaat en -oriëntatie, het gebruik van schermen en windsnelheid en -richting. Een aantal opties om de kastemperatuur te beheersen worden besproken. Met deze kwantitatieve informatie kunnen kasontwerpers en -bouwers en tuinders betere beslissingen nemen.

Abstract
The project "*Safe and accessible greenhouse production of (fruit) vegetables in Ghana*" ("*Fresh Green Ghana"*), among others, intends to achieve improvement and enlargement of protected horticulture through data sharing and technology improvement, including the post-harvest chain, in collaboration with growers. This can contribute to greater availability of fresh (fruit) vegetables for the urban poor in Ghana. Data on environmental conditions outside and inside four greenhouses in southern Ghana were obtained from January 2018 – August 2019. The most important environmental character is temperature. Outdoor temperatures vary between 21 and 35°C, and indoor temperatures can be up to 10°C higher. Such high temperatures are have negative effects on crop growth and production. Influencing factors are altitude, size and orientation of the greenhouse, use of screens, and wind speed and direction. A number of management options to reduce the temperature increase are discussed. With this quantitative information, greenhouse designers and constructors and growers are better informed to make the right decisions.

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Disclaimer

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Summary

Ghana knows temporal shortage of fresh (fruit) vegetables, leading to high prices for the poor and hence under-consumption. Open field cultivation has failed to give a response to the perennial problem of shortage of fresh vegetables. Protected horticulture enables economically and environmentally sustainable production through more and cheaper vegetables, generation of employment, and through the lower use of chemical crop protection agents. The project "Safe and accessible greenhouse production of (fruit) vegetables in Ghana" (short name: "Fresh Green Ghana") intends to achieve improvement and enlargement of protected horticulture through data sharing and technology improvement, including the post-harvest chain, in collaboration with growers. The project also wants to obtain insights in the role of youth and gender in greenhouse production systems and produce recommendations for improvement. These activities lead to greater availability of fresh (fruit) vegetables for the urban poor in Ghana during the year.

Data on environmental conditions outside and inside four greenhouses in southern Ghana were obtained from January 2018 – August 2019. The most important environmental character is temperature. Outdoor temperatures vary between 21 and 35^{o}C, and indoor temperatures can be up to 10^{o}C higher. Such high temperatures are have negative effects on crop growth and production. Influencing factors are altitude, orientation of the greenhouse, use of screens, and wind speed and direction. There are a number of management options to reduce the temperature increase, viz.

1. Adjust the farm size to appropriate dimensions. The width of the greenhouse in tropical lowland conditions is limited. Hot air enters from the sides and moves upward to leave the greenhouse through the top vent. If the width of the greenhouse is too large, the centre is never reached by the air coming from the sides. As the outside temperature becomes lower and wind speed higher, the greenhouse can be wider.
2. Diffuse plastic to reduce the level of direct radiation and improve light distribution over canopy depth, which improves crop photosynthesis rate.
3. Use of shades or screens to reduce radiation and temperature, and to improve light distribution and crop photosynthesis. Shades and screens can be placed above the greenhouse, in order not to hamper the ventilation rate. They can also be placed inside the greenhouse.
4. Orientation of the greenhouse, making sure that the ventilation effect is optimal
5. Cooling through:
   - Natural ventilation, which is for free, potentially maintains greenhouse temperature at about the same level as outdoor temperature, and manages humidity and CO_2.
   - Fogging by bringing small droplets of water into the greenhouse, which absorb energy and remove this energy from the greenhouse as the float to the outside. The problem is that fogging does not work when relative air humidity is already high. An additional disadvantage is the investments and the need for clean water.
   - Pad & fan and forced cooling cost energy and are therefore not a feasible option for most small greenhouses. It might be options for larger greenhouses where the overall technology and production levels are higher.

With the quantitative information that is presented in this report, greenhouse designers and constructors and growers are better informed to make the right decisions.

1 Introduction

1.1 Project background

1.1.1 Project summary

Ghana knows temporal shortage of fresh (fruit) vegetables, leading to high prices for the poor and hence under-consumption. Also the use of pesticides and poor post-harvest hygiene causes much concern for consumers, leading to again lower consumption. Over the years, open field cultivation has failed to give a response to the perennial problem of shortage of fresh vegetables. Protected horticulture enables economically and environmentally sustainable production through more and cheaper vegetables, generation of employment, and through the lower use of chemical crop protection agents. The project "Safe and accessible greenhouse production of (fruit) vegetables in Ghana" (short name: "Fresh Green Ghana") therefore intends to achieve improvement and enlargement of protected horticulture through data sharing and technology improvement, including the post-harvest chain, in collaboration with growers. The project also wants to obtain insights in the role of youth and gender in greenhouse production systems and produce recommendations for improvement. These activities lead to greater availability of fresh (fruit) vegetables for the urban poor in Ghana during the year.

1.1.2 Project description

1.1.2.1 Background and rationale

Vegetable cultivation provides an excellent source of employment for both rural and urban dwellers as it is grown in many rural areas as well as in the outskirts of towns and cities to be supplied fresh to the urban markets. Growing and consuming safe and nutritious vegetables in and around the cities also contribute to a dietary diversity, household food security and improve the urban poor's economic access to food. The vegetable industry in Ghana has three distinct components (Elings *et al.* 2015a). Commercial/ market gardening, medium scale production for contractors/middlemen and small-scale domestic / backyard gardening. Most of the farmlands in Accra, the capital city of Ghana are used for commercial cultivation of vegetables (tomatoes, okro, cabbage, lettuce). Traditionally, vegetables are mostly eaten processed or cooked both as a spicy tomato paste (Shitu) as well as 'soups' with banku or fufu. More recently, the urban population is turning to fresh salads. This is mainly a result of Ghana's sustained economic growth that has led to the emergence of a middle class of consumers demanding higher quality fresh produce. Production of fresh vegetables takes place all around the country and is strongly related to the specific weather conditions and market windows.

Currently, the issue that hampers the production and consumption of fresh vegetables in Ghana is the temporal shortage of produce caused, among other reasons, by limited agronomic skills and inadequate and scarce production technology. However, not only do inadequate production techniques (inadequate use of pesticides and fertilisers) hinder the access to safe vegetables, but so do the unstructured (vegetables and fruits) value chains to be found in Ghana leading to much waste. Poor connectivity among actors and limited flow of products reduce the urban consumers' ability to access safe and nutritious food. Production and value chain challenges lead to high prices during the dry season since vegetable cultivation is generally rainfed and low prices during the wet season. The result is an unmet demand for healthy and accessible vegetables for poor urban consumers all year round.

The (temporal) shortage of fresh and safe vegetables can be reduced through improved production systems. Protected horticulture improves the resource use efficiency: not only is the annual yield increased, but substantially lower quantities of water and nutrients are required to produce the same amount of produce.

Also, the greenhouse cover protects the crop from invading insects and therewith functions as a crop protection mechanism and reduces the need for (chemical) crop protection agents. The flipside of increased yields and higher resource use efficiency are the higher costs, both in terms of investment and operational costs. Still, business cases point out that vegetables can be produced provided a minimum greenhouse size and good farm management. Essential is the knowledge level of the farmers (and others involved): protected horticulture is not simple, and continuous attention is required.

Greenhouses for lowland tropical climates have been developed (e.g., Indonesia, Malaysia), just as they have been for other low to medium-technology environments (Elings *et al.* 2015b). An adapted design for Ghana is only possible if information on the biophysical climate is collected and current crop management are well described. There is serious lack of such information. Growers do not record the climate, and barely register crop management practices and farm economic data.

There is limited knowledge available about the gender of the actual work force with respect to vegetable production in greenhouses. An initial quick gender analysis can shed a light on gender based task division and intra-household benefit sharing of greenhouse vegetable production and -income. When women are heavily involved in the actual day-to-day duties, they could be used as information source on how to design new greenhouses in a gender sensitive manner. If women are not involved, a follow-up gender scan can provide more insight in the barriers that prevent women to become involved in greenhouse vegetable production.

This obviously hampers the design of a greenhouse production system that is particularly suitable for Ghanaian conditions. Importantly, the design of optimal production systems will respond directly to the needs of current and future practitioners, whose views and ideas will be fed back to the project (and vice versa) through the "so-called" multi-stakeholder approach. Practitioners (growers) are therefore directly involved in both data collection and design-improvement throughout the project.

1.1.2.2 Objectives

One of the focal points of the Multi-Annual Strategic Plan (MASP) of the Embassy of the Kingdom of the Netherlands for Ghana is 'Modernization of agriculture and food security', and it is mentioned that 'Horticulture is a good example of a sector in which the Netherlands can be involved in the entire value chain' (Embassy of the Kingdom of the Netherlands, 2014). The MASP strategy involves, among others, vegetables as a main subsector of mutual interest, and transformation of the agricultural sector by developing and strengthening the value chain, with a focus on productivity, quality and sustainability. This relates to the under-performing agricultural sector, the need of the poor (and others, of course) for vegetables, and modernization of the agricultural sector.

The project objectives are:
1. Improve all-year availability of affordable, safe fresh vegetables for the poor.
2. Modernize the protected cultivation sector.
3. Improve supply chains for the urban poor.

1.1.2.3 Research questions, methods and activities

The project objectives have been translated to a number of research questions, methods and activities to answer these.

Research question 1: What are the key characteristics of a greenhouse production system for fresh vegetables in Ghana?

Method: Collection and evaluation of data and insight in growers' practices.

Activities:
1. Install sensors in a variety of greenhouses and introduce record sheets for manual observation.
2. Collect scientific data (climate, production, pest and disease incidence, etc.).
3. Scientifically interpret data: what contributes positively and negatively to the production, for which conditions?

Research question 2: What are the design options for environmentally and economically sustainable greenhouse production systems and which are tailored to the needs of current and future practitioners and are gender sensitive?

Method: Interactive design process with practitioners.

Activities:
1. Analyse gender based constraints in accessing (modern) greenhouses.
2. Based on the gender analysis, determine gender sensitive strategies to enable women to access modern greenhouses
3. Determine design criteria together with growers (with focus on gender, environmental and economic sustainability).
4. Design different concepts. Determine design options for a greenhouse production system in Ghana (for different places) taking into account (male and female) practitioners' realities and needs. This does not only refer to hardware, but likely more to crop management, crop protection, packaging, and socio-economic differences between men and women, etc.
5. Stimulate implementation of improved modules in existing greenhouse production systems.
6. Feedback from growers on suggested concepts (hardware, software, org-ware), creating in iterative loop in the design process.
7. Stimulate implementation of improved modules in existing greenhouse production systems.

Research question 3: Do improved options for greenhouse production contribute to social, environmental and economic sustainability, and improved food security for the poor?

Method: Evaluate the economic performance of improved production systems.

Activities:
1. Monitor performance of improved production systems in terms of social, economic and environmental sustainability (including production, price levels and gender aspects).
2. Evaluate the effect on employment and income generation and intra-household decision making.

Research question 4: Can product quality and accessibility to the poor be improved by insight and improved design of the local supply chains.

Method: Evaluate current challenges in the supply chain and interact with practitioners for potential improvements.

Activities:
1. Collect quantitative and qualitative data of quality parameters in the supply chain (temperature fluctuations, photos of typical situations)
2. Interact with practitioners (market managers – 'Market Queens') based on modelled product quality decline and collected data to design alternative strategies and technologies/tools.
3. Evaluate improvement of product quality in the market place.

1.1.3 Report focus

This report focuses on research questions 1 and 2.

1.2 Participating farms

Four project partners made available their farms for monitoring and evaluation, viz.:
Safi Sana sees waste as a resource. It collects faecal and organic waste from urban slums and treats it in a digester to create organic fertilizer, irrigation water and biogas. The irrigation water and the organic fertilizer are used in a greenhouses. Within the project Safi Sana uses its local organizational capacity as well as greenhouse facilities to support the project and connect to the local vegetable markets. Its greenhouse measures 39 by 10 meters (390 m^2 in total), has a one-sided top vent and is equipped with a shade screen to reduce the level of direct radiation.

AgriImpact is a private company with experience in greenhouse production. It has a greenhouse training centre, a greenhouse incubation centre, and a number of established greenhouse demonstration centres. AgriImpact is be responsible for data acquisition with farmers, SMEs and institutions that will be involved in the project. Its greenhouses measure 39 by 10 meters (390 m^2 in total), has a one-sided top vent.

Premium Vegetables has a 5000 m^2 tropical greenhouse in the Aburi Hills just out of Accra. We are producing hydroponic tomatoes, green peppers and cucumbers. The high elevation and cool night temperatures has raised productivity significantly. Premium Vegetables will collaborate in evaluation and testing of greenhouse modules. Its greenhouse measures 5000 m^2 in total, and has a number of one-sided top vents.

Urban Jungle turns urban gardening into a business opportunity. We aim to produce healthy, affordable vegetables on (sub)urban plots. Accra has many plots that are earmarked for construction but are unused. Urban Jungle wants to agree with the owners to turn the patches into gardens, growing fresh vegetables for the local market. Urban Jungle will collaborate in evaluation and testing of greenhouse modules. Its greenhouses also measure 390 m^2 and have a one-sided top vent.

The University of Accra also joined mid-2019 in terms of monitoring and evaluation, without becoming a formal project partner. Data collected at the University of Accra are not part of this report, although they might appear in part of the figures.

All greenhouses have side nets for natural ventilation. AgriImpact and Premium Vegetables are located at a higher altitude than Urban Jungle, SafiSana and the University of Accra. With an average longitude of 5.72 the daily daylength does not deviate much deviate from 12 h.

Figure 1.1 *Pictures of greenhouses of Premium Vegetables, SafiSana, Urban Jungle and AgriImpact.*

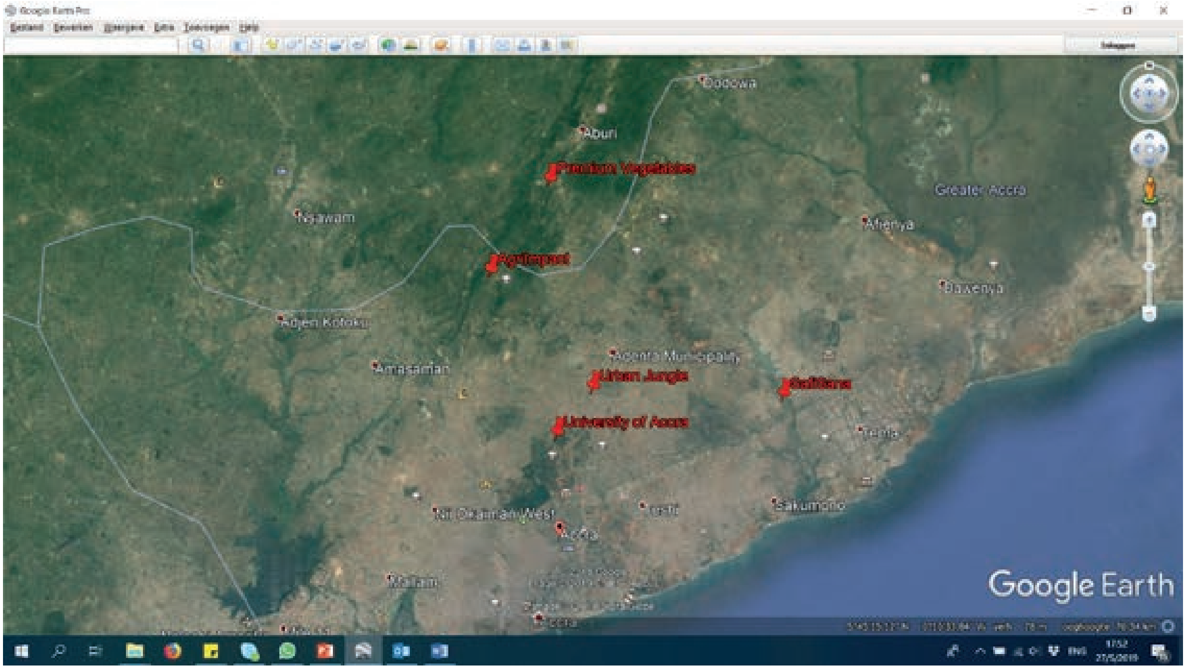

Figure 1.2 *The geographical location of the participating farms.*

Table 1
Summary description of the project greenhouses.

Location	Key characteristics	Area (m^2)	Altitude (m)	Orientation of top vents
AgriImpact	1 span	390	347	SE
Premium Vegetables	4 span, large area	5000	312	SSE
SafiSana	1 span, shade nets	390	16	SE
Urban Jungle	1 span	390	73	E
University of Accra	1 span		85	

1.3 Monitoring

The farms were at the beginning of the project equipped with:

a. A Tahmo automated weather station (tahmo.org) that observes and transmits environmental data on relative air humidity, precipitation, air pressure, global radiation, air temperature, wind direction and wind speed.
b. A temperature and air humidity logger (Testo 175 H1) to monitor air temperature and relative air humidity inside the greenhouse.

Data were gathered on an hourly basis and weekly processed to easy-to-read figures. At all times, both the raw data and the processed data were available to the project partners, who had the option to use this information in their greenhouse management.

This report presents data from 2018 and January - August of 2019.

1.4 Acknowledgements

The project was funded by NWO, the Netherlands Organisation for Scientific Research, from the Food & Business Applied Research Fund (ARF) Call 2016, under file number W 08.270.346. We thank all growers and partners for their collaboration, in particular for their support in data acquisition.

Figure 1.3 *A Tahmo weather station (left) and a Testo data logger (right).*

2 Monitoring results

2.1 Radiation

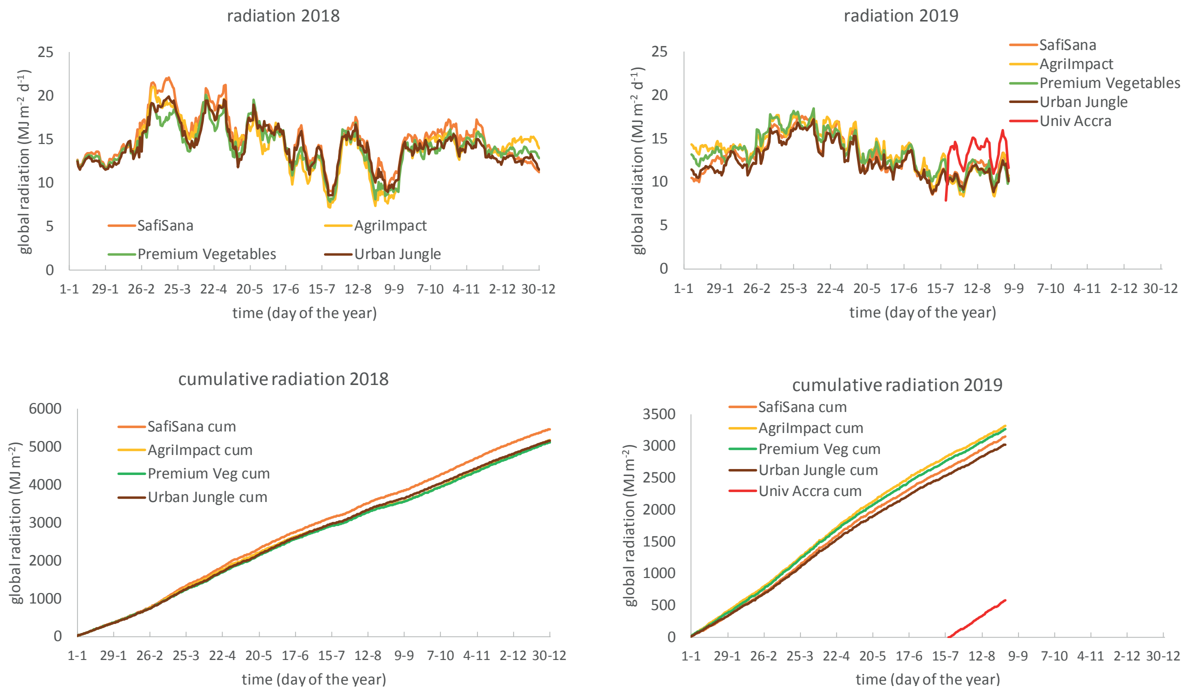

Figure 2.1 *Daily (above) and cumulative (below) global radiation at the five project locations1. Daily radiation is given as a 7-day running average.*

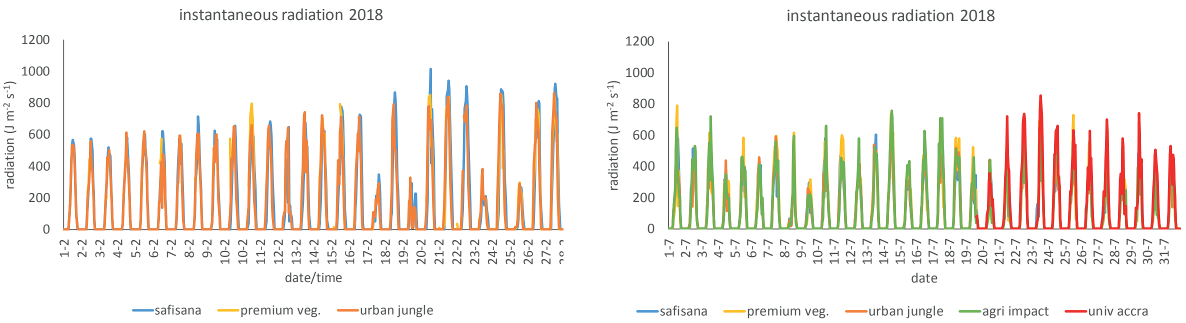

Figure 2.2 *Instantaneous radiation in February 2018, when radiation levels were relatively high, and in July 2019, when radiation levels were relatively low.*

Global radiation was measured outside the greenhouse and fluctuated between approximately 10 and 20 MJ m^{-2} d^{-1}. Instantaneous values of course vary over the day, peaking around noon to values that depend on cloud cover and solar position. Peak values can be as low as 200 J m^{-2} s^{-1} and as high as 1000 J m^{-2} s^{-1}. On average, the peak value varies between 600-800 J m^{-2} s^{-1}. Based on the 1½ years of data, differences between stations are not systematic. SafiSana received more global radiation than the other stations in 2018, however, this was not the case in 2019.

[1] For all figures and tables: the University of Accra joined only in the course of 2019. Cumulative values therefore start later. For 2019, only data of January – August are considered.

The radiation inside the greenhouses is much lower. The project did not measure the transmission of the greenhouse, but because of the construction elements, nets and dust on the greenhouse cover this is estimated less than 50%, which considerably reduces the light level. Daylength in the tropics is always about 12 hours per day, and therefore, the plants do not benefit from long daylengths. The Netherlands, in comparison, receives about 3500 MJ m^{-2} y^{-1}, which is a little higher. The long summer daylength compensates the short winter daylength. Greenhouses in The Netherlands generally transmit 70% of the light, and assimilation lights are used for an increasing number of crops to compensate for low light levels in winter. Besides many other things, this explains the high yield levels.

2.2 Precipitation

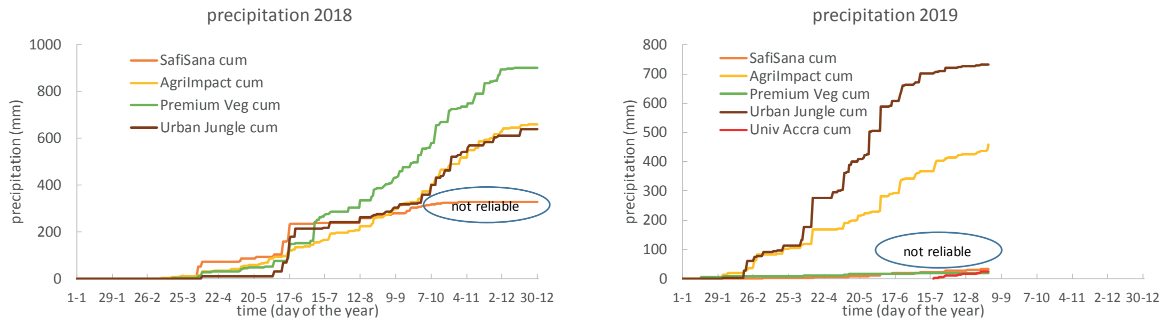

Figure 2.3 *Cumulative precipitation at the five project locations. Some data are not reliable.*

Values on precipitation are not reliable for all stations, unfortunately[2]. Annual precipitation varied in 2018 between 640 and 900 mm, with slight peaks in May and October. One would expect that high rainfall coincides with less radiation, but this is not the case. Radiation in 2018 reached low values in other months than May and October.

Rainfall is good irrigation water because it is not contaminated with diseases. It also has very low amounts of nutrients, which enables the farmer to realize the desired nutrient levels.

In greenhouse design, the intensity of rainfall determines the minimum requirements of the gutters, which should be large enough to cope with the water flow.

2.3 Air pressure

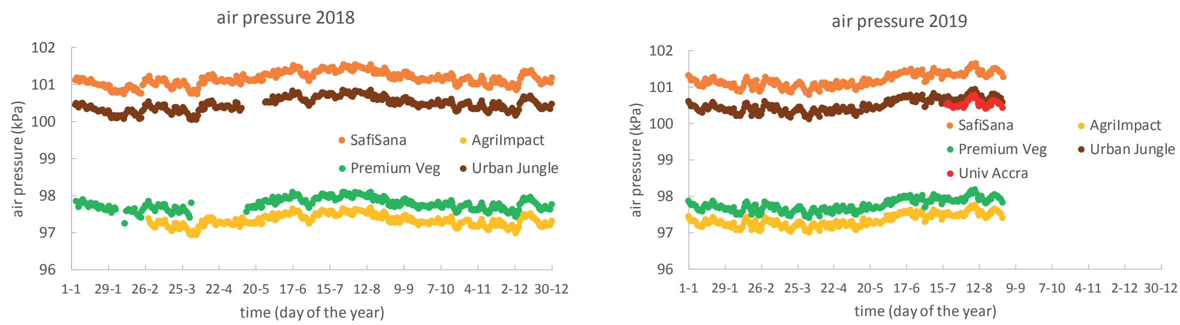

Figure 2.4 *Daily average air pressure at the five project locations.*

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[2] At the time of writing, a technician is inspecting the weather stations.

Air pressure is related to weather conditions and altitude. The difference between the two locations in the hills north of Accra, viz. AgriImpact and Premium Vegetables, and the more southern locations, viz. SafiSana, Urban Jungle and Accra University, is clearly visible. It is otherwise unlikely that these differences have an effect on the greenhouse climate.

2.4 Temperature

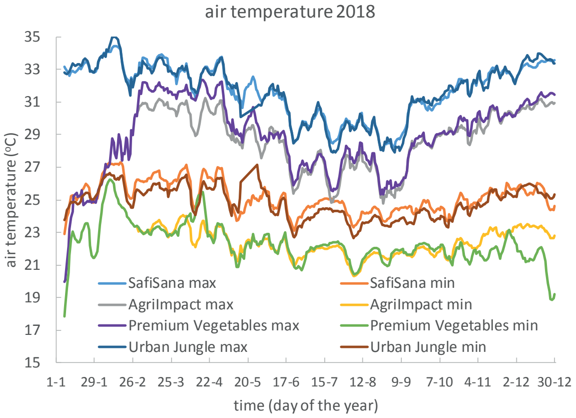
Air temperature is very important. Many physiological processes are sub-optimal or come to a halt at very high or very low temperatures. Low temperatures are not an issue in Ghana, but high temperatures obviously are. These might result in:

- Direct reduction of the photosynthesis rate.
- Closure of stomata if water supply is insufficient or of available water can not be transported fast enough to the leaves. This results in reduced exchange of CO_2 and a lower photosynthesis rate, and in a higher leaf temperature because of the lower evaporative cooling.
- Reduced fruit set because of problems with pollination, fertilization, meiotic processes, abortion, etc.
- Leaf deformation.
- Partly of complete senescence and crop failure.

Outdoor temperatures are a given fact, so issue is what indoor temperatures are caused by the greenhouse constructions.

2.4.1 Outdoor temperature

Air temperature outside the greenhouses were different for the different locations, and were roughly related to the altitude of the locations (see also under 'air pressure'). Lowest daily maximum and minimum temperatures were observed for the two locations in the hills north of Accra, viz. AgriImpact and Premium Vegetables, while the more southern locations, viz. SafiSana, Urban Jungle and Accra University, faced temperatures that were 2-3°C higher. This seems little but can make a large difference in case crop growth and development processes are critical.



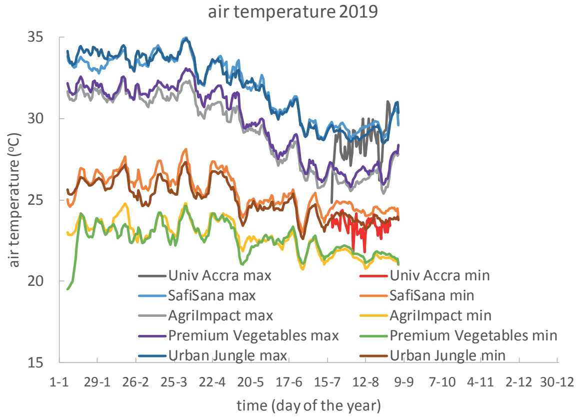


***Figure 2.5** Daily maximum and minimum outdoor air temperatures at the five project locations. Values are given as a 7-day running average.*

Table 2

Annual average maximum and minimum outdoor air temperatures (oC) at the five project locations.

Location	Max 2018	Min 2018	Max 2019	Min 2019
AgriImpact	28.81	22.35	29.35	22.73
Premium Vegetables	28.72	22.18	29.85	22.51
SafiSana	31.75	25.13	31.94	25.51
Urban Jungle	30.28	23.62	31.93	25.02
University of Accra			28.51	23.40

2.4.2 Indoor temperature

Loggers to register indoor temperature were not always functioning well. But we gathered sufficient data to assess the effect of the greenhouse construction on temperature. In figures below the following information is presented:
Figure 2.6: Hourly outdoor and indoor temperature.
Figure 2.7: Hourly difference between outdoor and indoor temperatures.
Figure 2.8: Examples of hourly indoor and outdoor temperatures that were largely similar and very different.

In order of increasing temperatures:
SafiSana: Indoor temperatures around mid-day were at most 5°C higher than outdoor temperatures, reaching values between 35 and 40°C in the warmer periods of the year. Indoor temperatures in the cooler periods of the year may be between 30 and 35°C.
Premium Vegetables: Indoor temperatures around mid-day were often 7.5 - 10°C higher than outdoor temperatures, reaching values between 35 and 40°C.
AgriImpact: Indoor temperatures around mid-day were often 8 - 10°C higher than outdoor temperatures, reaching values between 35 and 40°C (or higher).
Urban Jungle: Indoor temperatures around mid-day were often 7.5 – 12.5°C higher than outdoor temperatures, reaching values between 40 and 45°C.

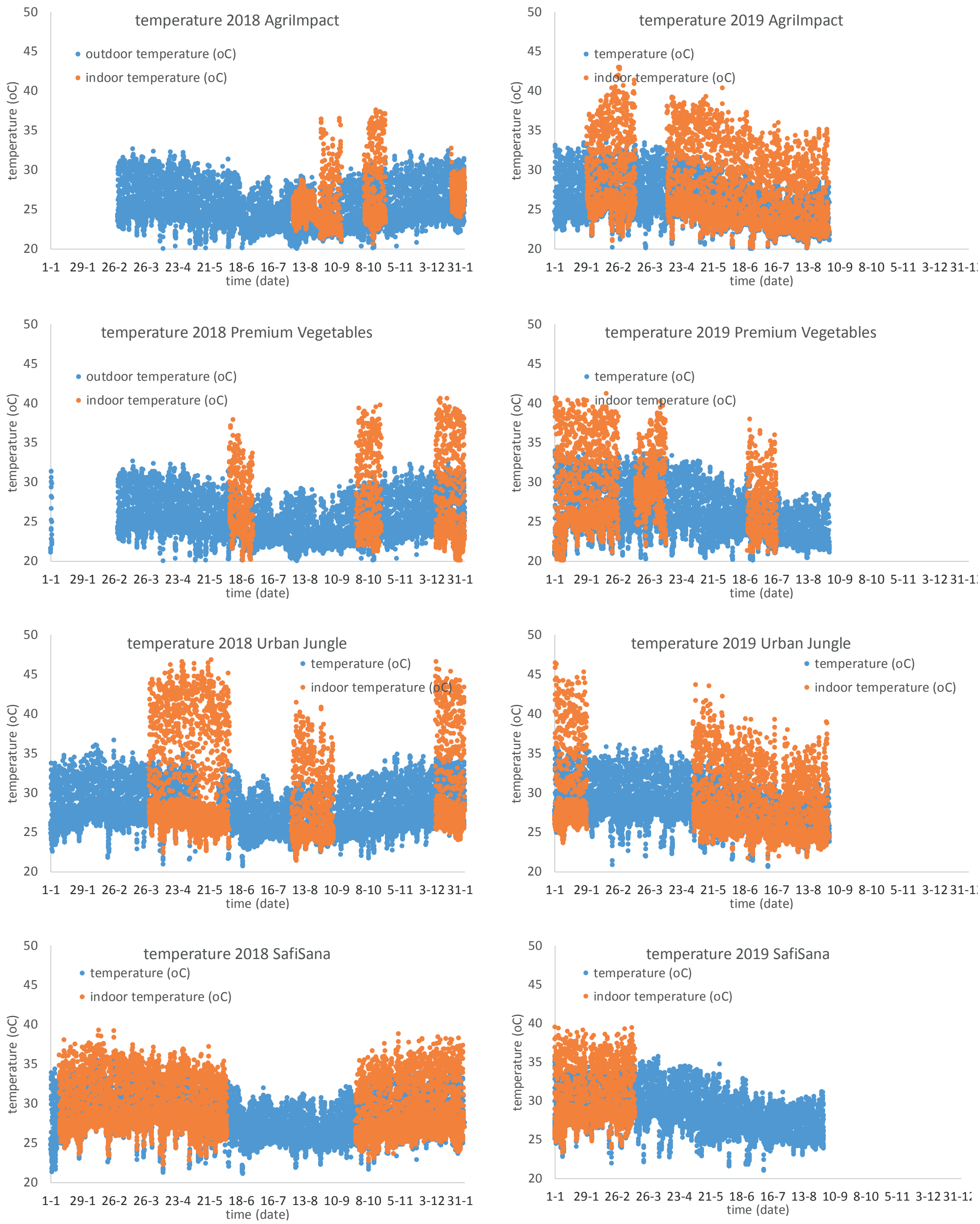


Figure 2.6 *Hourly outdoor and indoor temperatures during 2018 (left) and 2019 (right) for four project locations (all but Accra University).*

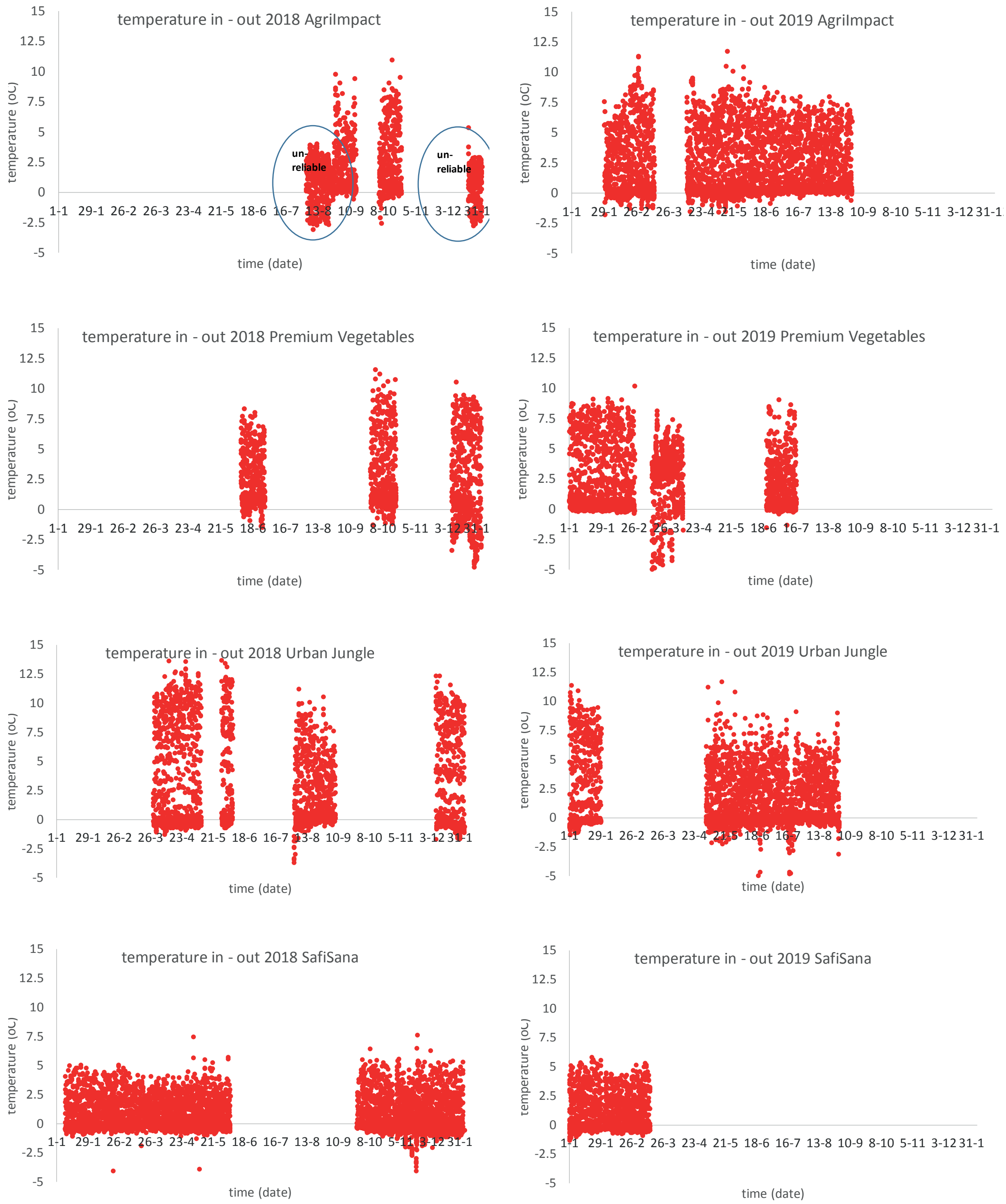


Figure 2.7 *Hourly difference between outdoor and indoor temperatures during 2018 (left) and 2019 (right) for four project locations (all but Accra University). Data are presented only when both outdoor and indoor temperature were available.*

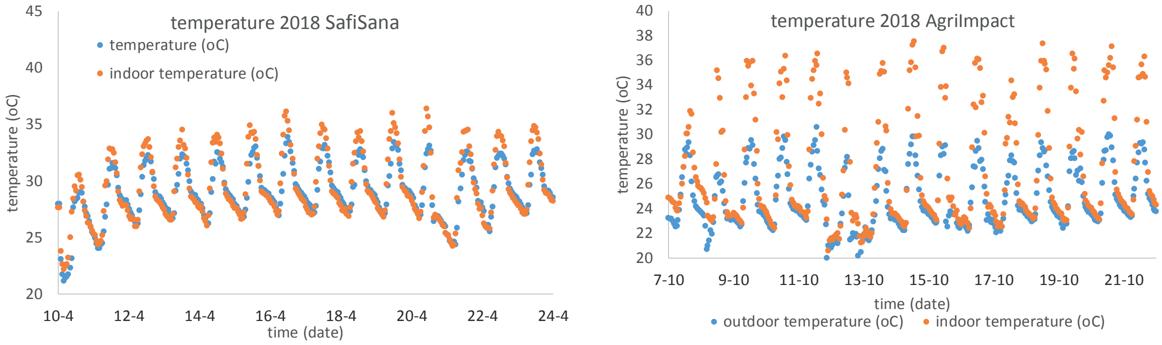


Figure 2.8 *Examples of hourly indoor and outdoor temperatures that were largely similar (left) and very different (right).*

2.5 Air humidity

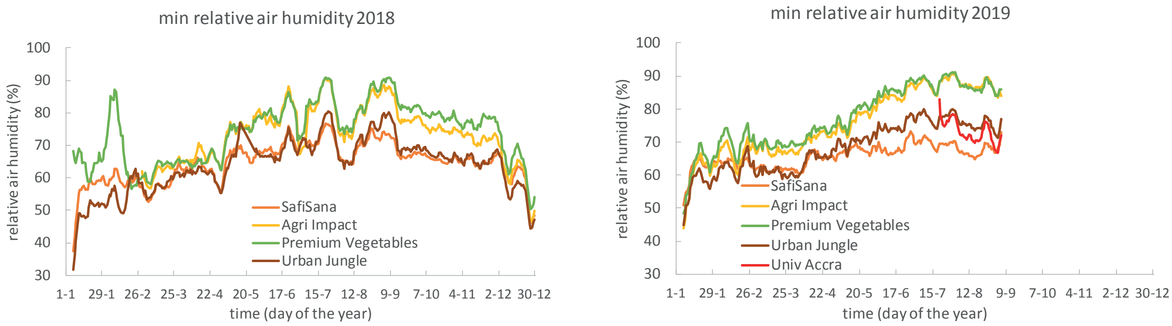


Figure 2.9 *Daily minimum relative air humidity inside the greenhouse at the five project locations. Values are given as a 7-day running average.*

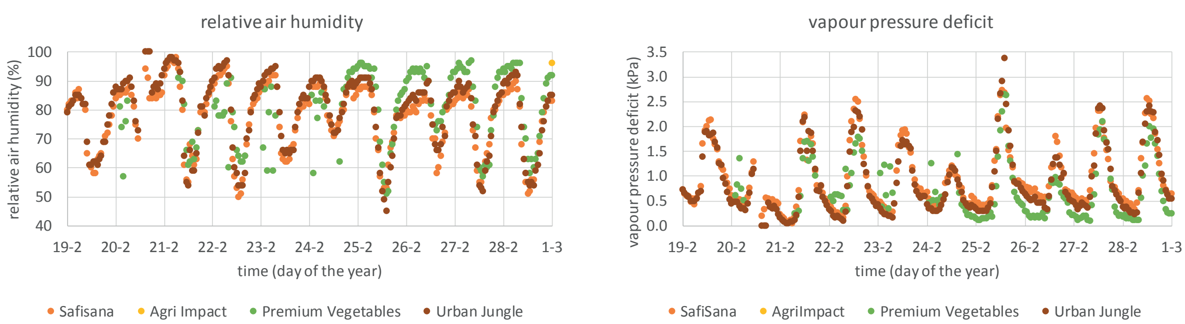


Figure 2.10 *Examples of hourly values of relative air humidity (left) and vapour pressure deficit (right).*

Daily maximum relative air humidity (RH) was mostly between 80 and 100%. In 2018, the annual average value for AgriImpact was 99%, for Premium Vegetables 97%, for Urban Jungle 93% and for SafiSana 90%. Daily minimum relative air humidity, characteristic for mid-day circumstances, was a little lower for SafiSana and Urban Jungle than for Premium Vegetables and AgriImpact in the hills. During the year, minimum relative air humidity peaked during June through September.

For crop growth, which is determined by the rate of photosynthesis (CO_2 assimilation), the relative air humidity itself is not very important. The vapour pressure deficit (VPD) is. VPD is the difference (deficit) between the amount of moisture in the air and how much moisture the air can hold when it is saturated[3]. The VPD increases with increasing temperature and decreasing relative air humidity. Figure 2.10 shows some days with hourly RH and VPD values. RH and VPD reach minimum and maximum values, respectively, around noon. Stomata respond to VPD and close at high values, and moreover, may not open again in the afternoon. Measurements would have to be conducted to obtain certainty on the behaviour of stomata and the consequences for photosynthesis. Peaks in VPD were mostly highest for Urban Jungle, and lowest for Premium Vegetables.

2.6 Wind direction and speed

The wind direction at Premium Vegetables was predominantly SE, whereas at the other locations it was predominantly N to E. Wind speed was relatively low at Premium Vegetables. Wind speed at Urban Jungle was intermediate, whereas it was highest at SafiSana and AgriImpact.

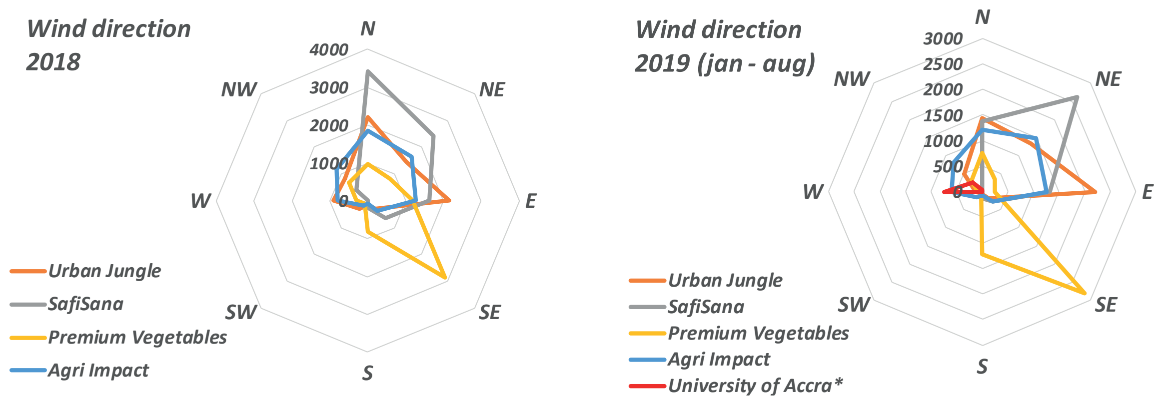


Figure 2.11 *Spider web presentation of cumulative, hourly wind directions at the five project locations.*

3 https://en.wikipedia.org/wiki/Vapour-pressure_deficit.

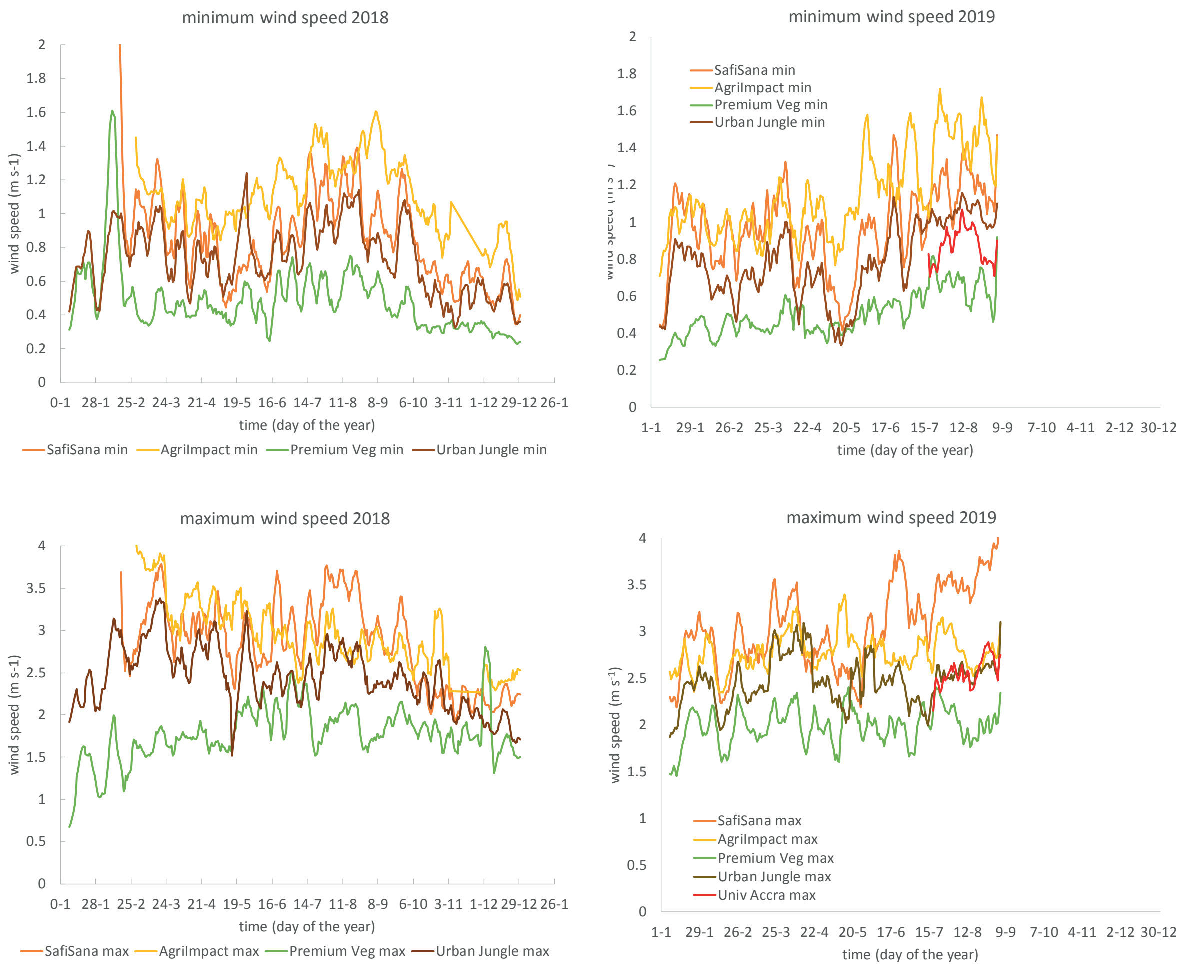


***Figure 2.12** Daily minimum (above) and maximum (below) wind speed at the five project locations. Values are given as a 7-day running average.*

Table 3
Position of the top vent in relation to the dominant wind direction.

Location	Dominant wind direction	Actual orientation of top vents	Preferred orientation of top vents
AgriImpact	N to E	SE	S to W
Premium Vegetables	SE	SSE	SW
SafiSana	N to E	SE	S to W
Urban Jungle	N to E	E	S to W

For relatively small greenhouses, it is best if the wind moves over the top vent. Then fresh air will come in from the sides, move up and leave from the top vent. If the wind blows into the top vent, the warm air can not easily leave the greenhouse. The project greenhouses should therefore benefit from a different orientation (Table 3).

3 Recommendations for greenhouse design

3.1 Analysis of monitoring data

Temperature management in the greenhouse is everything in the hot lowland tropics of Ghana. Temperature is influenced by a number of environmental factors and knows a number of potential management options (Elings, 2015b).

The location of the greenhouse determines a number of influencing factors

1. Air temperature outside the greenhouse. Outside air temperature can not really be influenced and has to be taken for granted.
2. Altitude. Air temperatures outside the greenhouses in the hills north of Accra were 2-3°C lower than at sea level. This may not seem a lot, but can be important if growth conditions are critical.
3. Wind speed. Premium Vegetables had the lowest wind speed, followed by Urban Jungle. Wind speed depends very much on local circumstances, which are in the case of Urban Jungle determined by the housing around the farm.
4. Vapour pressure deficit peaks at all locations, but most at Urban Jungle. Whether this is critical, is difficult to conclude without detailed measurements.
5. Global radiation, that introduces long-wave heat into the greenhouse. There is no systematic difference between the locations in Ghana. The use of diffuse plastic with good UV-protection is a good choice.

Management options:

1. Adjust farm size to appropriate dimensions. The width of the greenhouse in tropical lowland conditions is limited. Hot air enters from the sides and moves upward to leave the greenhouse through the top vent. If the width of the greenhouse is too large, the centre is never reached by the air coming from the sides[4]. As the outside temperature becomes lower and wind speed higher, the greenhouse can be wider (see for example Premium Vegetables).
2. Diffuse plastic to reduce the level of direct radiation and improve light distribution over canopy depth, which improves crop photosynthesis rate.
3. Use of shades or screens to reduce radiation and temperature, and to improve light distribution and crop photosynthesis. It can improve quality of the produce, and some crops even prefer shade. Shades and screens can be placed above the greenhouse, in order not to hamper the ventilation rate. They can also be placed inside the greenhouse, as SafiSana has done.
4. Orientation of the greenhouse. The position of the top vent in relation to the dominant wind direction (Table 3). Premium Vegetables has positioned its top vent towards the dominant wind direction, which causes wind movement from the top into the greenhouse; it might have been better to turn the greenhouse by 180°. The other greenhouses are not positioned very well, as the dominant wind direction is on the average NE and the vent is oriented almost perpendicular to this. Premium Vegetables has the problem of slightly lower wind speeds than the other locations.
5. Cooling through:
   - Natural ventilation, which is for free, potentially maintains greenhouse temperature at about the same level as outdoor temperature, and manages humidity and CO_2.
   - Fogging by bringing small droplets of water into the greenhouse, which absorb energy and remove this energy from the greenhouse as the float to the outside. The problem is that fogging does not work when relative air humidity is already high. An additional disadvantage is the investments and the need for clean water.
   - Pad & fan and forced cooling cost energy and are therefore not a feasible option for most small greenhouses. It might be options for larger greenhouses where the overall technology and production levels are higher.

[4] https://www.ingreenhouses.com/digitalmagazines/?wur=true#dflip-df_33935/28/.

3.2 Feed-back of farmers and suppliers

The results were presented and discussed at the workshop 'Greenhouse Production Systems Round Table Meeting' at May 29, 2019, organized by Fresh Green Ghana and HortiFresh[5]. This workshop was attended by 50 participants, among which farmers and suppliers. The report of this gathering, with a summary of the presentations, is given in Annex 1.

The greenhouse sector in Ghana is maturing. In comparison with a few years ago, farmers and suppliers appeared more realistic, possible as a consequence of some years of experience. This is a healthy development. It was broadly acknowledged that the greenhouse sector is thriving and has much potential, but that much additional experience still has to be gained. One option is the establishment of a demonstration centre where technology and best practices can be evaluated and knowledge specific to Ghana can be generated. The technological issues presented in this report and at the workshop were well-acknowledged. Having said that, this does not imply that they have been truly absorbed by the sector. To achieve this, much more knowledge transfer will be required – a task for the remainder of the project.

Another point of debate is the financial business case (Elings *et al.* 2015a, Herms *et al.* 2016), which was also extensively discussed at the workshop. The author's personal belief is that greenhouse production can be financially sustainable, provided high-quality yields are sufficient and investments are kept to the minimum.

[5] www.hortifresh.org

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Annex 1 ‘Greenhouse Production Systems Roundtable Discussion’

Date: May 29, 2019

Venue: Alisa Hotel

Organization: HortiFresh West Africa and Fresh Green Ghana

Facilitator: Hanson Arthur, Fund Manager HortiFresh

Participation: 50

Introduction
Protected cultivation is gaining ground rapidly in Ghana. It is believed that across the country, over the last years, hundreds of tunnels and greenhouses have been built. the case of the private sector, our day to day contacts with vegetable farmers indicate that there is a ‘buzz’ in the sector that tunnels and greenhouses are highly profitable. Also, the public sector increasingly wants to stimulate protected cultivation. It is seen as a good way to get youth involved in agriculture and produce more and better quality vegetables.

Fresh Green Ghana is a Dutch and private company funded project that seeks improve Ghanaian protected horticulture and supply for the urban population through data and knowledge sharing on production systems and gender, and through addressing post-harvest challenges. In this, it closely collaborates with growers. The project has been collecting information on growing conditions in relation to the ambient environment outside the greenhouse in a number of greenhouse production system. It also has obtained information on the transport conditions in post-harvest value chains, and on gender and youth aspects of the greenhouse production system.

HortiFresh West Africa is a Dutch funded program that seeks to achieve the goal of a sustainable and internationally competitive fruit and vegetable sector that contributes to inclusive economic growth, food and nutrition security. In the previous phase of HortiFresh, studies were carried out on the comparative analysis of open field versus greenhouse production, provided insightful knowledge on the sector. The projects would like to share and discuss this knowledge with a larger group of greenhouse growers and other stakeholders such as suppliers of greenhouses and other inputs, governmental representatives, extension officers, and representatives of the educational bodies. The projects hope that this stimulates the further development of greenhouse production systems that will contribute to the Ghanaian horticultural sector.

The aims of the roundtable meeting were to share learnings on optimizing greenhouse vegetable production and post-harvest value chains, and discuss gender integration in the greenhouse production system, leading to the development of roadmap and definition of further actions to stimulate improvements in greenhouses, production and post-harvest value chains.

Outline of the Roundtable
The roundtable commenced with a welcome by Hanson Arthur, HortiFresh and individual introductions by the participants present. He proceeded to provide a brief overview of the HortiFresh program and the previous project GhanaVeg to the participants. The welcome was followed by a keynote address by Mr. Amatus Deyang, Director of the Department of Agricultural Engineering of the Ministry of Food and Agriculture.

The keynote speaker, in his address presented the Government of Ghana’s plans to improve protected cultivation in country. He outlined the plans including trainings for 51 graduates in Isreal on greenhouse production and management. Greenhouses are being imported into the country and set up on farmers’ fields for use.

The objectives of the roundtable was presented by Zipphora Aseidu, Program Manager of Fresh Green Ghana.

[6]Presentations

1. Comparative Analysis of Existing Greenhouse Models in Ghana
by Joep van den Broek of Resilience BV.
Mr. van den Broek provided a cost-benefit analysis between the Dizengoff & Envirodome tunnel greenhouses. It was noted that based on the dimensions of the greenhouses, profitability can only be achieved between 4 – 7 years. Details can be found in http://ghanaveg.org/wp-content/uploads/GhanaVeg_Business-Case-2_Greenhouses.pdf?x42440 .

***2. Greenhouse Expert's Outlook* presented by Jeroen Baas**
Mr. Baas shared the ways Ghana can improve protected cultivation. He presented the current outlook being a small high –end market for greenhouses but faces competition from the regional market. He also proposed focusing on a niche market and growing it into steady market, consider the cultivation of local leafy vegetables and focus on the branding of greenhouse products.

***3. Perspectives from Private Sector* by Mr. Selorm Agudu of Urban Jungle Agro**
Mr. Agudu focused on the weakness and threats in the sector. He called for there to be a customized approach to greenhouse production for Ghana. He relayed that there is little to no knowledge on the greenhouses in the Ghanaian climate but rather imported knowledge which may not be best suited to the country. He also pointed out that the protocol suggested for greenhouse production does not translate into the Ghanaian situation. He called on MoFA to aid the farmers in combating key issues that are facing greenhouse farmers such as the problem of thrips in Sweet pepper production.
One notable key action that Mr. Agudu spoke about was the formation of a Greenhouse Farmers Association in Ghana to serve the needs of producers using greenhouses in the country.

***4. Experiences on Greenhouse Climate: Project results* by Dr. Anne Elings of Wageningen UR Greenhouse Horticulture.**
Dr. Elings focused on the factors that affect the temperature within the greenhouse. The presentation compared different greenhouse types, choice of materials, location and agronomic practices carried out within the greenhouse and its impact on temperature within the greenhouse. The greenhouses were located at different organizations in the Southern part of Ghana; Safi Sana in Ashiaman, Urban Jungle in Dawhyena, Agrimpact in Brekuso, University of Ghana in Legon and Premium Vegetables in Dodowa. He concluded that in order to reduce temperatures in the greenhouses, the owners or producers should consider the following; more ventilation capacity, location relative to the dominant wind direction, location, weather, type of screening, maintenance of crop transpiration into consideration. Overall, the use oflarger greenhouses should be considered.

***5. HortiFresh Greenhouse Financial Product* by Rosina Obeng of HortiFresh.**
This presentation was on a component of the HortiFresh programme with the objective of supporting companies in the Fruits &Vegetable sector with access to finance. There are two main components are financial products and individual component support. The financial products are the greenhouse financial product, vegetable input package, exporter-outgrower product and the solar irrigation production. The greenhouse financial product is aimed at producers who want to move from open field to protected cultivation or want to scale up on their greenhouse production.

***6. Learnings on Value Chains and Youth & Gender* by Thomas Tichar of Wageningen UR Centre for Development Innovation.**
This presentation reviewed the findings on a study conducted on the gendered differences in greenhouse production. It also studied the matching skills and interests of both males and females based on the market need. It concluded that there is some mismatch between training and greenhouse requirements, and that gender bias can on the one hand encourage managers to hire women, but on the other hand that gendered norms may keep women out of working in the greenhouse sector because of perceptions of it being a more male-oriented place.

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[6] The presentations should become available at the website of the Food & Business Knowledge Platform (https://knowledge4food.net/research-project/arf3-fresh-green-ghana/).

General Discussion

1. **Action Points**
    - A broad case study that involves various greenhouse types should be considered.
    - One major issue is the low number of skilled greenhouse labour for greenhouse production. Labour can be obtained but there is no skilled training for greenhouse. There is the need for apprenticeship training.
    - Change in educational system. Agriculture must be included in the curriculum from Junior high school to Senior high school level. The Dutch embassy is working with GIZ to restructure the curriculum at the farm institutes and agricultural colleges.
    - There is a proposal to develop a case study on the economic value of involving women in greenhouse production.

2. **Suggestions**
    - A suggestion was made of having young people trained in areas with climates similar to that of Ghana so they can learn greenhouse cultivation.
    - A counter suggestion of rather bringing people to Ghana who understand our climate its impact on Ghana to make tailor made solutions that will work for our environment.
    - Privatization of value chain services (private agronomy services) where young people are trained to deliver critical services.
    - The use of local materials in the construction of greenhouses, for example, the use of bamboo.

3. **Wrap-up**
    - There were strong reactions from the participants about the comparative analysis stating that it is not all gloom and doom as there are private sector individuals who are contributing immensely to the sector.
    - Greenhouses are high-impact, high output agriculture so the knowledge systems/access is key.
    - There are clear do’s and don’t in greenhouse farmers, but there is also a lot of needs to be based on the field experience. One example is temperature considerations.
    - Good examples of greenhouse operations exist in Ghana but the sector is still young. There is still more to learn.
    - Economic/ cost-benefit considerations are important. The research/data exists for sector actors to make informed decisions.
    - Access to finance support is available; HortiFresh provides the linkage to the financial institutions.
    - Greenhouse sector is emerging as a key area of youth employment and gender –sensitive horticulture, but there is need to consider the following:
        - Ownership by women and youth.
        - Research for other adaptable sources of raw materials; bamboo, wood etc.
    - Skills for young men and women – through mentorship or apprenticeship are key. Maybe instead of Israel, trainees can go for similar climatic zones
    - More local research is needed to build local knowledge/skill base.

Further Steps

Ghanaian greenhouse horticulture is in a distinctly different phase than a few years ago. The sector has gained experience, sometimes the hard way, resulting in a more realistic perspective on avenues for further development and on hurdles to overcome. Sector representatives are convinced that a sustainable development of the sector is possible, in which they are supported by the Ghanaian government and by existing and emerging support industries, training institutes and the educational system.

Factors that influence sector development are, amongst others:

- Benefits: market price development, market development for a diversity of crops.
- Costs: low-costs greenhouses and installations, low maintenance.
- Skills and knowledge: capable staff and management, at all levels in the industry; training programmes, local knowledge build-up.
- Greenhouses: appropriate design that is suited to the Ghanaian climate; better assessment of environmentally and economically sustainability of greenhouse production system.
- Crop management: realize good application of water and nutrients, good pest and disease management, good crop maintenance, etc.
  - Value chain: secure relations between grower and merchant, maintenance of product quality.
  - Youth: stimulate youth employment along the horticultural value chain.
  - Gender: remove gender mis-matches.
  - Collaboration: work along with farmers and their associations.

An action plan to further enhance greenhouse sector development would include the following elements:

- Increase understanding of achieving a profitable greenhouse production system.
- Strengthen the emerging Greenhouse Farmers Association, Ghana.
- Develop greenhouse designs that fit in the Ghanaian climate and lead to environmentally and economically sustainable greenhouse production systems.
- Establish a demonstration centre that evaluates different greenhouse options and can serve as a centre of excellence.
- Improve the continuous availability of high-quality inputs.
- Increase the levels of skills, knowledge and awareness.
- Develop reliable value chains.
- Stimulate youth employment along the value chain.
- Deal with gender mis-matches.

There is already a wide variety of activities in the greenhouse sector in Ghana. Numerous growers run a greenhouse production system, mostly supplying to the high-end market, and with variable levels of success. Fresh Green Ghana and HortiFresh West Africa are Dutch-funded programmes that currently support sector development. Universities, Colleges and a number of companies (e.g., AgriImpact, AgriTop) are involved in research and training. Private companies (e.g., Dizengoff, Envirodome) are in the business of greenhouse construction and input supplies. The Ghanaian government is supporting development through, for example, the establishment of three greenhouse areas. Netherlands companies (e.g., GreenSpan) are placing their first greenhouses. MDK Flowers & Greens is active in Ghana since 2006.

All these activities are motivated by the firm belief that there is market demand for high-quality fruit and leafy vegetables in Ghana.

The sector will benefit from a coherent approach through a joint vision on the medium to long-term goals and on the short to medium-terms activities to be employed. A number of such activities will require support from both the public and private sector.

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