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What is the Future of Rain-fed Horticultural Crops Production in a Changing West African Climate? : A Review

Chinedu Felix Amuji[1,2]

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ABSTRACT

Within West Africa (WA), poverty, population growth rate and food insecurity are high and most agriculture is conducted at an un-mechanised level, reliant on rain-fed conditions. As with elsewhere around the world, there is a clear fingerprint of climate change on WA, with increasing temperatures and shifts in precipitation patterns. As the century progresses and climate change intensifies, so too will the impact on rain-fed horticulture. This creates an urgent need to understand and synthesis the responses of horticultural crops to climate change and identify adaptation options. This review provides an overview of climate change across WA and the impacts on key horticultural crop groups (vegetables, plantations, fruits and root and tubers) and identifies regions within WA where these crops may be more or less vulnerable to changing conditions. Adaptation actions and strategies- ranging from education, introduction of new cultivars and development of effective cropping systems, to transference of skills from other regions and expansion of farmer-government-NGO collaborations are discussed.

Key words: Climate change, Food security, Horticulture, Rain-fed conditions.

West Africa (WA) is recognised as one of the most vulnerable regions to anthropogenic climate change (Niang *et al*., 2014; Sultan *et al*., 2014; Turco *et al*., 2015), due both to its geographical position (Sultan and Gaetani, 2016) and socio-economic factors such as rapid population growth and relatively low levels of industrialization (Joiner *et al*., 2012). In addition, the WA has experienced 0.16°C per decade increase in mean annual maximum temperature and 0.28°C per decade increase in mean annual minimum temperature, in the last 50 years, as well as more frequent heatwaves and declines in the number of cold days (Barry *et al*., 2018). In some areas within the region, annual precipitation has fallen 20-40 per cent compared to 1970's levels and there have been substantial deviations in monsoonal precipitation, along with increases in storm and flooding events across tropical and coastal zones and prolonged and frequent drought within arid zones (USAID, 2018).

Continental WA (5° N - 35° N and 15° E-15° W; Fig 1) is composed of 14 countries: Benin, Burkina Faso, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast (Cote d'Ivoire), Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo. Bounded in the north by the Sahara Desert and the south by the Atlantic Ocean, this region is home to about 30% of the African population and 5% of the world's population (United Nations, 2015). Over recent decades, WA has experienced high population growth ranging from 2.7 to 3.0% per annum (p.a.) (Knippertz *et al*., 2015) and is expected to reach 490 million of people by 2030 (Hollinger and Staatz, 2015). However, the human population and natural resources are distributed unevenly throughout the region.

Agriculture throughout West Africa is influenced by geographical location, the people involved and their socio-economic background, interactions between people and the environment and the evolution of the biodiversity. Agriculture is a primary and fundamental component of the economies of most countries of the region, contributing up to 35% of their total gross domestic product (GDP) (Hollinger and Staatz, 2015) and providing employment for 65% of the population (Asare-Kyei *et al*., 2017). Currently, more than 70% of all agricultural production activities are conducted at an un-mechanized level, with little to no irrigation facilities (Blein and Bwalya, 2013; Sossa *et al*., 2017). As such, advances in agricultural production have been limited, leading to flow-on problems associated with food productivity and security, which are often identified as a major cause of insurgence uprising (Okpara *et al*., 2016). Yet, agriculture remains a low priority among the policies of individual national governments for eradication of poverty, economic diversification, empowerment and security, environmental sustainability and management (Blein and Bwalya, 2013). For example, public spending on agriculture in Nigeria – measured by percentage of agricultural expenditure in agricultural Gross Domestic product (GDP) – is amongst the lowest in the world Olomola *et al*., 2014).

[1]Department of Crop Science, Faculty of Agriculture, University of Nigeria Nsukka, Enugu State, Nigeria.
[2]Department of Biological Sciences, Faculty of Science and Engineering, Macquarie University Sydney, NSW 2109, Australia.

Corresponding Author: Chinedu Felix Amuji, Department of Biological Sciences, Faculty of Science and Engineering, Macquarie University Sydney, NSW 2109, Australia.
Email: felix.amuji@gmail.com

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Horticulture comprises a major sector within plant agriculture (Von Baeyer, 2014) and plays a key role in the generation of personal income, earning of foreign exchange, employment provision and food security. Major horticultural crops from West Africa for consumption and export include tomato (*Solanum lycopersicum*), potato (*Ipomoea batatas*) and onion (*Allium cepa*), as well as a growing trade in cassava products and yam (Olasantan, 2011). Presently, as with other forms of agriculture in this region, the moisture requirements of these crops are primarily met through precipitation rather than irrigation. However, climate change is highly likely to impact rain-fed cultivation. Hence, climate change has the potential to be a substantial disruptive influence on some of the poorest and most politically insecure, countries in the world (Levy and Patz, 2015).

Here, I review the current state of knowledge of the potential impacts of climate change on rain-fed horticultural crops in West Africa. I consider the likely scenarios of future climate change that might affect the region over coming decades, the responses of key horticultural crops to recent climate change and projections of future changes of crop yields and habitat suitability. I also identify adaptation strategies and initiatives that may aid in policy development and promote food security at national to regional levels.

West African land use

Population growth in WA has placed increasing pressure on natural ecosystems (Chen and Ravallion, 2004), with land cover and land use throughout WA being mostly driven by agricultural production and intensification. This has resulted in the conversion of large portions of natural vegetation to agriculture (Cotillon and Tappan, 2016). For example, over the 40-year period from 1966–2007, land under cultivation increased from 8.4 to 11.8%, with notable changes including the conversion of the transhumance corridors of the Sahel eco-zones to farmland (d'Ivoire *et al*., 2007) and the destruction of many primary forests in the humid zone, precipitating a shift from closed to open forest and then to woodland (d'Ivoire *et al*. 2007). In addition, between 1980-2000, over 10% of closed forests were transformed into open forests and 3 to 7% of fragmented forests to woodland (FAO, 2006).

Paradoxically, ecosystem services and resources are highly valued and utilized in the region for livelihood, food, provisioning of fuel for cooking and building of shelter among others (Muthee *et al*., 2018). Additionally, resources obtained from the ecosystems may be sold or exchanged to supplement household income (Egoh *et al*., 2012). This dependency highlights the urgent need for an effective and sustainable management of natural resources to avoid over-exploitation (Western, 2003). Such management practices include the development of agro-ecosystems and the establishment of annual horticultural crops (e.g. tomatoes, okra, soybean), which can be planted in a controlled environment like glasshouses to prevent continuous land clearance that has obvious consequences for natural systems (Arsanjani, 2011).

Observed and projected climatic trends

The climate of the West Africa is strongly influenced by the West African Monsoon (Sultan and Gaetani, 2016), in addition to temperature and precipitation being controlled by global ocean and air temperatures (Pomposi *et al*., 2015). The region is defined by four distinct eco-zones running west to east across the continent. In the south and bordering the Atlantic Ocean lies the Guinean and Guineo-Congo eco-zones. These two zones contain belts of tropical forest (Hansen *et al*., 2008) (Fig 1) and are characterized by high precipitation and humidity. While the wettest areas may have precipitation exceeding 2000 mm p.a. (Akinsanola and Ogunjobi, 2017; Sossa *et al*., 2017), this gradually decreases with increasing latitude. North of the Guinean eco-zone lies

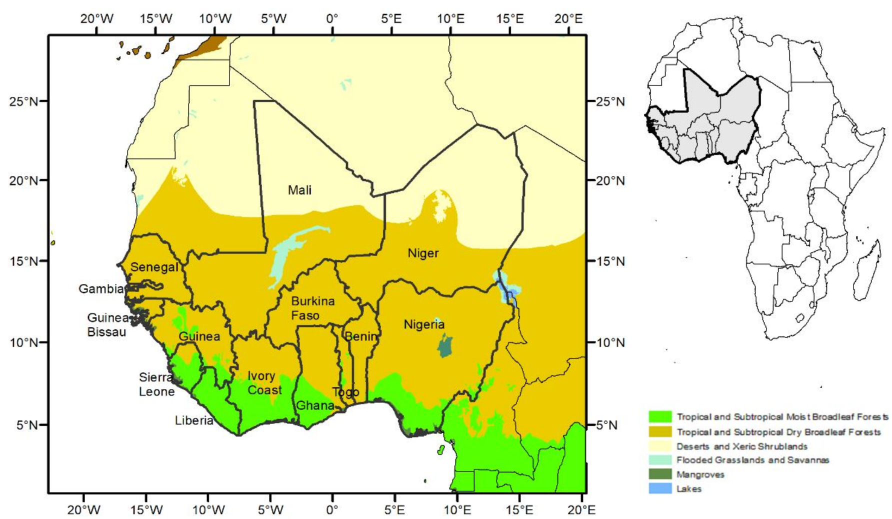

Fig 1: Countries of West Africa with major biomes.

the Sudan eco-zone with its open wooded savannahs and perennial grasses (Diaconescu *et al*., 2015; Akinsanola and Ogunjobi, 2017), which gives way to the annual grasses of the drier Sahel eco-zone (Alam *et al*., 2013). North of the Sahel, the Saharan eco-zone is marked by sparse to absent vegetation and with less than 150 mm precipitation p.a. (Cotillon and Tappan, 2016).

Temperature effects

Temperature across WA is strongly determined by global ocean sea surface temperature (SST) (Pomposi *et al*., 2015). Over recent decades, a clear warning signal has emerged across some regions, with the Gulf of Guinea and west Sahel experiencing the greatest rates of warming of 0.2-0.5°C per decade since the 1980s (Sylla *et al*., 2016). In contrast, there appear to have been no significant changes in the southern Sahara and northern Sahel (Sylla *et al*., 2016).

Within the next 20-30 years, the region's semi-arid and arid (*i.e.* Sahel and Saharan eco-zones) zones may serve as future warming hotspots, where annual mean temperature may increase by additional 2-4°C under a higher greenhouse gas emissions pathway (Sarr, 2012; Mora *et al*. 2013). During the last three decades of the 21st century, 60% of summer months across Sub-Saharan Africa are projected to be hotter than five standard deviations above the 1951–1980 baseline under the high-emissions pathway (Serdeczny *et al*., 2017). In contrast, most of these extremes are likely to be avoided under a low-emissions pathway (Serdeczny *et al*., 2017).

Precipitation trends

The Sahel and Saharan eco-zones typically have a single rainy season each year around July. In contrast, the Guinean and Guineo-Congolian eco-zones have two wet seasons. The first generally runs from late April to early May, when the West African monsoon brings rain along the Atlantic Guinean coast (Froidurot and Diedhiou, 2017). The second rainy season extends from June to early July, after which it returns to the Sahel eco-zone within days (Cook, 2015).

Precipitation variability characterises rainfall throughout WA, with substantial shifts from wet to dry periods. For example, patterns cycled from a wet period throughout the 1930–1960s, to the devastating droughts of the 1970s–1980s, with consequential impacts on the people, agricultural production and the environment (Rodríguez Fonseca *et al*., 2011). Precipitation then swang back to a more 'normal' regime in the mid-1990s (relative to the 1901–1998 average) (Sarr 2012).

Simulations of changes to the African Monsoon between 2030 and 2070 indicate that precipitation may decrease in the western Sahel and increase in central-eastern Sahel (Monerie *et al*., 2012). Toward the end of this century, daily precipitation is projected to decline over the Gulf of Guinea (Raj *et al*., 2019). According to Ekwezuo *et al*. (2017) the West African mean annual maximum and minimum rainfall pattern are ~2600 mm and ~50 mm respectively. The projected changes in mean annual rainfall pattern show that rainfall amount increases over the Guinea coast and decreases inland (Ekwezuo *et al*., 2017). However, there is considerable variation regarding future precipitation patterns in the region, with projections from climate models spanning -30 and 30% of baseline levels, though larger variations are expected in the Sahel (Sylla *et al*., 2016).

Climate change projections for West Africa under alternate RCPs and GCM (*i.e.* emissions scenarios and climate models)

West Africa is subject to uncertainties associated with the Global Climate Models (GCMs) (Macadam *et al*., 2020). According to Macadam *et al*. (2020), this is primarily due to the use of different climatic variables for parametrization schemes, resulting in substantial uncertainties in GCM projections. For instance, under the Representative Concentration Pathway 8.5 (RCP8.5), models project temperature in the Sahel ecozone to increase between <0.5-4°C by 2040-2065, relative to 1951-2000 (Rowell *et al*., 2016). However, this increase in temperature maybe less for other ecozones within the region (Sultan and Gaetani, 2016). The IPCC Fifth Assessment Report (2014) showed that under RCP 8.5, the northern part of the region towards the Sahara Desert is likely to have an increase of 4 to 7°C by 2081 to 2100 from baseline of 1986 to 2005. However, the southern part towards the coast is likely to have a smaller increase of between 2 to 3°C within the same period of time. Under RCP 8.5, GCMs project, on average, an increase in annual precipitation of 10 to 50% across the north-west region of WA by 2081 to 2100, compared to the 1986 to 2005 baseline. However, there is little consensus across GCMs in the direction of change. In the southern and eastern part of the region towards the coast, the precipitation changes are projected to be between -10 to +10 % during the same period of time (IPCC, 2014).

Projections for the future indicate that there may be a general increase in heatwaves, both in frequency and intensity, over the West African region (Odoulami *et al*., 2017). Studies on present climatic conditions indicate that areas within the Guinea ecozones of WA are less likely to experience heatwaves than areas further north such as the southern Sahel to northern Sahara (Sylla *et al*., 2018). Similarly, the number of days with heatwaves in the future will be greater over the Sahel and Sahara Desert ecozones than in the Guinea ecozones (Odoulami *et al*., 2017; Sylla *et al*., 2018). This increase in heatwaves may have potentially important implications for food security and crop diversity in the West Africa region. This is inferred from previous modelling studies that suggested reductions in crop yields due to increases in temperatures (Sultan *et al*., 2013). However, interacting climatic factors, such as rainfall distribution, episodic drought, humidity and evaporation rates will also influence the outlook for food production.

Horticultural crops in WA

In WA, the horticultural crops with the highest production in terms of tonnes are root and tuber crops. According to

FAOSTAT (2019), over 93 million tonnes of cassava (*Manihot esculenta* Crantz) and 66 million tonnes of yam (*Dioscorea* species) were produced in 2018. Excluding cereals and legumes, between 2-10 million tonnes of 12 other horticultural crops were also produced in 2018: plantain (*Musa paradisiaca*) (>9.7 million), sugar cane (*Saccharum* species) (>6.7), sweet potato [*Ipomoea batatas* (L.) Lam.] (>5.5), tomato (*Solanum lycopersicum* L.) (>5.2), taro [*Colocasia esculenta* (L.) Schott] (>5.0), cocoa bean (*Theobroma cacao* L.) (>3.3), pineapple [*Ananas comosus* (L.) Merr.] (>2.9), okra [*Abelmoschus esculentus* (L.) Moench] (>2.7), onion (*Allium cepa* L.) (>2.7), mango (*Mangifera* species) (>2.5) and potato (*Solanum tuberosum* L.) (>2.1).

In general, countries within the Guinea and Sudan eco-zones of WA produce crops at a higher yield than those within the Sahel and Saharan eco-zones, particularly for root and tuber crops (cassava, yam and taro). Further, West African countries are among the world's leading producers of yam and taro (Fig 2). In the following sections, horticultural crops are classified as vegetables, plantation, fruit and root and tuber crops and the potential consequences of climate change on these crops within WA is assessed.

Vegetable crops

As with other crops, the production of vegetables depends mainly on soil and climate (Prodhan *et al*., 2018) with climate also influencing the development and condition of the soil through weathering (Dixon *et al*., 2009). Vegetables are generally highly sensitive to environmental extremes (De la Pena and Hughes, 2007) and increases in temperature will be a serious threat these crops in WA (Diallo *et al*., 2016) both directly and by exacerbating soil dryness (Monerie *et al*., 2016). Crops such as tomatoes grown in Sahel regions of WA already experience conditions at their upper optimal thermal margin. Additional increases in temperature will, therefore, result in lower yield (Amuji *et al*., 2020).

Other important vegetables crops that may be affected by the projected increase in temperature and dryness are peppers, onions, water melons and carrots (Erickson and Markhart, 2002). However, crop responses will depend on the plant growth stage and the exposure time to the stressing agent (Pandey *et al*., 2017). Under water-limited conditions, low water-use vegetables such as Tepary beans (*Phaseolus acutifolius*), black-eyed beans (*Vigna unguiculata*), okra (*Abelmoschus esculentus*) and asparagus (*Asparagus officinalis*) are likely to have higher survival rates (Elias *et al*., 2019).

Plantation crops

Plantation crops, also referred to as perennial horticultural crops [*e.g*. banana (*Musa* sp.), plantain (*Musa paradisiaca*), cocoa (*Theobroma cacao*)], are extremely sensitive to changes in temperature, water availability, solar radiation, air pollution and CO_2 (Glenn *et al*., 2013). This sensitivity affects both the quantity and quality of their harvested produce. Increased temperature, together with dryness and drought, can be a serious growth hindrance for plantation crops, reducing fruit and leaf development and may increase plant mortality (Ranjitkar *et al*., 2015).

Banana, plantain and cocoa are important components of diets among West Africans. These crops provide essential nutrients including vitamins, fibre and anti-oxidants (Martínez-Cardozo *et al*., 2016), which often are limited in cereals (Glenn *et al*., 2013). These crops are also very important for local and national economies (Brun *et al*., 1991). Lower rainfall will affect the growth and development of banana and plantain (German *et al*., 2015), with subsequent declines in yield. Conversely, should projected increases in precipitation across parts of the Sahel be realized, yields of these crops may increase (Raj *et al*., 2019).

West Africa contributes ~70% of the total global cocoa supply (Schroth *et al*., 2017) and production within WA is projected to increase by 3.7% in next 50 to 70 years (ICCO, 2018), which is considerably more than other regions of the world (*e.g*. 3.1% in America, 1.5% in Asia and Oceania, ICCO, 2018). However, if projected future declines in precipitation exceed 110 mm per month with increases in the frequency and intensity of drought events, there will be substantial impacts on the yield of this drought-intolerant crop (Carr and Lockwood, 2011, Gateau-Rey *et al*., 2018).

Fruit crops

In general, fruit crops such as mango, guava and especially citrus, are likely to benefit from higher concentrations of CO_2 due to the 'fertilisation effect' that this gas has on plant ecophysiology (Downton *et al*., 1987). However, the ability to realise positive responses to higher CO_2 may be offset depending upon the magnitude of temperature and precipitation changes. For instance, temperatures above 30°C can cause premature ripening in mango and dryness can induce reduction leaf initiation, leaf size and thickness in citrus (Rajan, 2012; Malhotra, 2017).

For most fruit crops, particularly those originating in the tropics which are adapted to temperatures of up to 30°C, deviations from their required optimum is likely to negatively affect production and quality while those crops currently limited by low temperature are likely to benefit from warming (Nath *et al*., 2019).

Root and tuber crops

Root and tubers make a substantial contribution to the diet of people in WA, with cassava, yam and sweet potatoes being key crops in this category. Yam, for example, plays an important role in food security and the livelihood of more than 60 million people within the region (Sanginga, 2015). In addition, West African countries contribute substantially to the global market for these crops (FAO, 2000). Benin, Ivory Coast, Ghana, Nigeria and Togo currently produce around 57 million tons of yam (about 93% of global production) and Nigeria accounts for approximately 68% of the global production (40.5 million tons produced across 3.2 million ha) (Sanginga, 2015) (Fig 2).

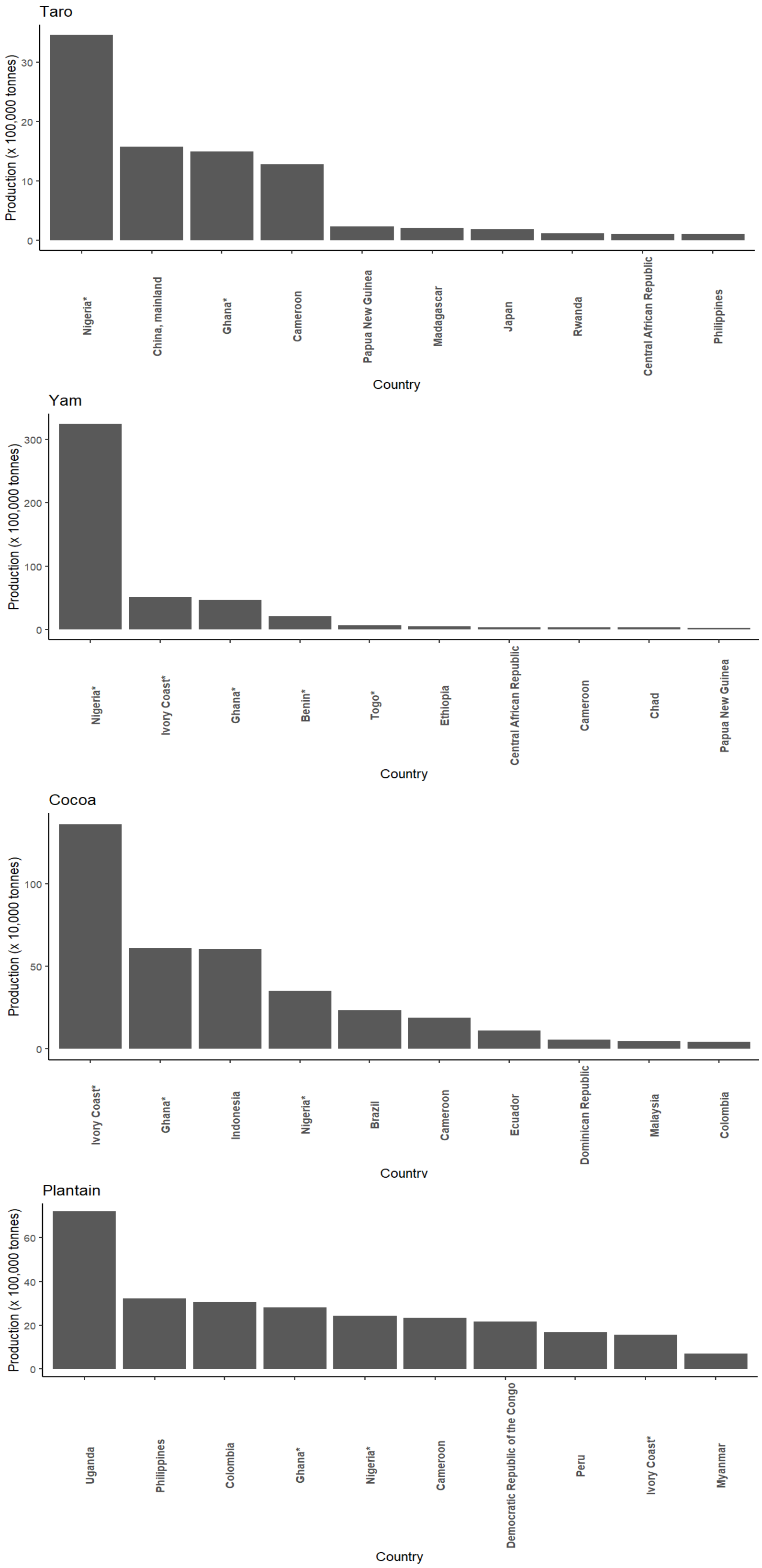

Fig 2: Production of key horticultural crops.
Average 1994-2017. Y-axis=total production in tones, X-axis= World's top 10 producing countries.
*Countries in West Africa (Source: FOASTAT, 2019).

Models of yam yield under climate change scenarios suggest that optimal temperatures for this crop (between 25-30°C) are likely to continue to occur in WA until at least mid-century (Srivastava *et al*., 2016). However, compared to the baseline of 1961–2000, yam yields across the savannah zone are projected to decline 18-48% by 2041-2050, due to reduced precipitation and nitrogen deficiency (Srivastava *et al*. 2012).

For cassava, increases in mean annual temperature of more than 1.5°C could negatively impact production (El-Sharkawy, 2003). In addition, glasshouse experiments indicate that plant biomass and tuber yield decline with higher CO_2 concentrations, due to a decrease in assimilation (Gleadow *et al*., 2009). Furthermore, concentrations of cyanogenic glycosides in the leaves of this crop also increase under high CO_2 concentrations, indicating that to remain edible the leaves may need processing in the future (Gleadow *et al*., 2009).

While used as a food source within West African countries, sweet potato is not yet a regional or internationally traded crop from West Africa (Sanginga, 2015). Both sweet potato and cassava are relatively drought tolerant, although tuber yield and starch content may be reduced when rainfall is limited (Malhotra, 2017). Hence, regions where precipitation has been projected to decline (*e.g*. southern and western Sahel part of the region, Monerie *et al*., 2012; Raj *et al*., 2019) may experience lower yields of these crops in the future.

Recommended adaptation strategies for WA horticulture

Within WA there is considerable effort in developing measures to mitigate the effects of climate change, *e.g*. through the formation of West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), which is a large scale research centre designed tackle to climate change challenges in the region. WASCAL's main objective is to undertake research on adapting land use and management of land given the region's changing climatic conditions (https://wascal.org/). However, a considerable number of areas have not been fully addressed, or need to be improved upon. These include:

Climate change education

Education related to climate change must increase and be reachable for all the stakeholders involved in horticultural crop production in West Africa, especially the farmers. This is very important as many studies have shown farmers' perceptions of climate change and adaptation influence the success of mitigation strategies (Niles and Mueller, 2016; Hitayezu *et al*., 2017; Waibel *et al*., 2018). In a region where illiteracy levels are very high, there is an urgent need for increasing the scope and means of convening the message of a changing climate. This task can be achieved through organizing workshops, seminars, conferences, compulsory formal classes for lower and higher school levels and informal sensitization through the mass media like television, radios, posters, *etc*. (Mailumo *et al*., 2018).

Provision of irrigation facilities

Supplementary water provision may be necessary for the success of some horticultural industries in West Africa, particularly in those areas where seasonal precipitation may decrease and episodes of drought increase, such as the southern Sahel (Raj *et al*., 2019). This provision will likely be vital for succulent horticultural crops, such as vegetables, that are significantly affected by water limited-conditions or stress (Waśkiewicz *et al*., 2016). However, expansion of irrigation facilities will require investment by governments and international agencies.

Introduction of new cultivars

There is a need to improve understanding of the physiological and genetic basis of crop adaptation to abiotic stress caused by climate change. As the climatic suitability of a region for its current suite of crops changes, different cultivars may prove more suited. This may necessitate a broader selection of crops being made available through breeding or introduction of new cultivars or varieties.

Adoption/development of effective cropping system

Climate change may modify crop production areas and timing of farmers planting thereby increasing the need to educate farmers on both impacts and solutions of the effects. There is also need to ensure that market mechanisms are in place should farmers need to adjust the range of crops they grow. Other management practices such as crop rotation, soil management and conservation and effective handling of pests and diseases infestation should be promoted to mitigate the adverse effects of climate change.

Improve research on climate change

Research on climate change must be supported and encouraged. This research should aim to develop new farming systems and sustainable alternatives for agricultural activities. More grants and funding availability will also increase the research in the area of possible climate effects on horticulture for the region.

Transferring and implementing new techniques/ knowledge/skills from other regions/countries

Efforts should be made at regional and national levels to assess and implement adaptation programs adopted by other countries. Many developed countries have already gained substantial knowledge on adaptation of horticultural crops to climate change and the transfer of lessons learned from these regions may help to reduce knowledge gaps for WA.

Proper collaborations

All stakeholders involved in horticultural industries, including farmers and those in the public and private sectors, should partner to generate and communicate management strategies in West Africa. This should involve organizations like FAO, CGIAR (Consultative Group for International Agricultural Research), UNEP (The United Nations Environment Programme) and WASCL. An example of such an initiative already in existence is the 'Forum for the Future' program. This non-government organisation works with governments, corporate businesses and civil societies in order to achieve a sustainable future (www.forumforthefuture.org). A holistic approach is needed in tackling the impacts of climate change to ensure that all sectors of horticultural production are addressed.

CONCLUSION

Climate change is likely to affect West African horticultural crops grown under rain-fed conditions. For some eco-zones, such as the Sahel, future climate scenarios predict increases in precipitation (Biasutti, 2013), which will likely have positive impacts on crop yields if temperature increases are not severe. However, across other regions, higher temperature and lower precipitation, combined with increases in the frequency and severity of extreme events, may have catastrophic consequences on the development of rain-fed horticultural crops. The uncertainty surrounding scenarios of precipitation necessitates that agile adaptation programs be developed. As the climate continues to change, continuous production of horticultural crops in their current regions under natural rain-fed conditions may no longer be a viable option.

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