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Agricultural Yield Responses to Climate Variabilities in West Africa: A Food Supply and Demand Analysis

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Abstract: Agricultural productivity is expected to decrease under changing climate conditions that correspond to the stability of West African food systems. Although numerous studies have evaluated impacts of climate variability on crop yields, many uncertainties are still associated with climate extremes as well as the rapid population growth and corresponding dietary lifestyle. Here, we present a food supply and demand analysis based on the relationship between climate change, crop production, and population growth in three sites from southwestern Burkina Faso to southwestern Ghana. Climate and agricultural time series were analyzed by using boxplots mixed with a Mann–Kendall trend test and Sen's slope. Food balance sheets were calculated by estimating the demand using a population growth model linked to food supply with local consumption patterns. We found almost insignificant rainfall and temperature trends for both sites in the Sudano-Guinean savannah. Conversely, the climate regime of southwestern Ghana revealed a strong significant increasing temperature over time. Crop yield trends demonstrated that maize and sorghum were significantly enhanced in both study areas of the Sudano-Guinean savannah. Southwestern Ghana depicted a different crop pattern where cassava and plantain showed a strong upward yield trend. The grouped food balance sheets across the regions illustrated a surplus for the Sudano-Guinean savannah while southwestern Ghana exhibited a deficit. Despite the growing yield of various crops, food demand is outpacing regional production.

Keywords: agriculture; climate variability; crop yield; food supply and demand analysis; West Africa; Ghana; Burkina Faso

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1. Introduction

Changes in climate patterns have fundamental impacts on agriculture that affect the rural livelihood in West Africa. The increasing frequency of droughts, irregularities in onset and shortening of the rainy period combined with a high reliance on rain-fed agriculture and weak institutional power, or limited adaptive capacity, make many regions less favorable for crop production [1,2]. A study by [3] projected under two representative concentration pathways (RCP 4.5 and RCP 8.5) for the Dano catchment in West Africa showed a decreasing annual rainfall rate of 25% with a temperature increase of about 1.3 °C to 1.5 °C by 2049. To mitigate these impacts, the 2014 Malabo declaration, as the main instrument of the Comprehensive Africa Agriculture Development Programme, aims to allocate 10% of African public resources to enhance agricultural productivity [4]. Without any adaptation of farming practices, climate effects will cause a regional yield loss close to 11% by 2050 [5].

The deep connection between climate variability, crop yield, and management turns the area of West Africa into a hotspot with severe land degradation processes as well as socio-economic challenges [6]. However, the agricultural sector remains the backbone of most economies in Sub-Saharan Africa and employs roughly 60% of the workforce [7]. Smallholder farmers produce the majority of staple food with a dominance of cereals such as maize, millet, rice, sorghum, and wheat [8]. For instance, the long-term trend of crop production between 1961 and 2022 in Burkina Faso revealed for maize, millet, rice, and sorghum an enhanced quantity of 2314%, 365%, 1355%, and 390%, respectively [9–11], reported for the country where the growing yield resulted from land expansion and not from any farming improvements such as fertilization or irrigation practices.

Non-climatic factors such as population growth, changes in the dietary pattern, and food demand will accelerate the human-induced transition to agricultural land [12,13]. The population growth rate for West Africa is forecast to increase approximately three-fold by 2050 with high expected values for Niger, Nigeria, and Burkina Faso [14]. This will influence the availability of food and generate a structural imbalance between crop yield and demand. In West Africa, the number of undernourished people rose from 32 to 56 million between 2009 and 2018, which renders the region quite vulnerable to food insecurity [15].

Many governments of West Africa have confronted the food consumption gap through a variety of measures such as banning crop exports or procuring subsidized inputs. With regard to these threats, sub-regional bodies adopted the common agricultural policy (ECOWAP) in 2005 as a basis for improving crop yield productivity and sub-regional collaborations for technology sharing [16]. In tandem with the West African Alliance for Climate Smart Agriculture, both initiatives intend to promote research on farming practices that will contribute to sustainable agro-ecosystems and the welfare of farmers [6].

In this study, we aimed to investigate the food supply–demand relation based on the nexus between climate variability, agricultural production, and population growth in Burkina Faso and Ghana. Many research studies have connected climate change impacts on rural regions with food security [17], analyzed the risk of climatic conditions on crop suitability, and confirmed that savannah crops such as sorghum or groundnuts are most affected in northern Ghana. For the same region, [18] studied the relationship of flood recessions and food security related to water management activities. Another host of recent studies revealed that food insecurity mostly occurred in rural areas due to inappropriate infrastructure and food storage systems, as well as donor tensions or reduced incomes [19,20]. From a different view, [21] investigated the link between climate change and farming activities with an emphasis on the perception of local farmers to support the agricultural and nutritional requirements in Burkina Faso. In line with these studies, [22] concluded that the gap of agricultural yield shortfalls relative to demand will increase for starchy crops such as rice in West African countries.

Uncertainties exist in studying projected climate change impacts on crop yield and in the adaptation of agricultural systems to future climate conditions. For example, fixed climate emission scenarios such as the RCP8.5 projection only capture the impacts of the average changes in climate without the relevant temperature and rainfall features. Several studies neglect weather extremes but many crops have a narrow range of climate variations corresponding to an optimal growth [23]. In this regard, many approaches focus on cereals, groundnuts, or some tubers without including other crops such as vegetables [24]. Additional constraints are associated with the projection of rapid population growth and the respective dietary lifestyle that determines the food demand within climate risk zones.

The objective of this study goes beyond existing uncertainties and literature on climate variability, yield data, and food supply–demand in two ways. First, we practiced an empirical analysis of various weather and crop time series using boxplots as well as the trend patterns to characterize the performance of the agricultural sector over time. Second, the statistical findings were balanced with regional population information to evaluate food supply and demand in three selected case study sites. Based on the relationship between harvested yield of cultivars, population growth, and demand, we were able to assess consumption deficits as well as surpluses. Subsequently, these results are compared with management practices, agricultural policies, and climate trends.

2. Materials and Methods

In this section, we introduce the research sites situated along different agro-ecological zones and the design of the methodological approach including a brief description of time series data to perform this work. The framework aims at bringing together climate variables, crop yields, and food consumption patterns with household census information to understand the interplay of food supply as well as demand across both countries.

2.1. Study Areas

The study was carried out in three experimental regions from southwestern Burkina Faso to two areas in Ghana (Figure 1). The Dano site, as one of the research catchments of the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL), is positioned in the Ioba province of Burkina Faso. The Bolgatanga/Bongo districts are located in the Upper East Region (UER) of Ghana, while the administrative units Nzema East/Ellembelle/Jomoro are parts of the Western Region. Corresponding to the Köppen–Geiger classification, the areas are dominated by a tropical-savannah or tropical-monsoon zone [25]. Dano as well as Bolgatanga/Bongo share a similar unimodal distinct rainy season from late April or early May to October and a dry period for the remaining months [26–28]. The mean rainfall ranges between 900 mm to 1200 mm and reaches its peak in July or August [29,30]. Annual temperatures of the Sudano-Guinean savannah, where both research sites are placed, oscillate between 20.1 °C to 38.4 °C [31]. The rainfall pattern for the three districts in southwestern Ghana consists of two wet seasons from March or April to July and a shorter rainy period from September to November with a dryer spell in August. From the coastal line to inland, precipitation lies within 1200 mm to 1400 mm while the air temperature ranges between 25 °C and 29 °C [32].

Livelihood activities in the Sudano-Guinean belt are mainly determined by rain-fed agriculture with a low level of mechanization. Over recent decades, farmland has massively increased to meet the demand of a rising population with annual growth rates of around 3% [33–35]. At the same time, intensification practices such as agricultural soil and water conservation practices have enhanced crop production. The principle crops are millet, sorghum, maize, rice, and legumes, for example groundnut or cowpea. Apart from food production, cotton cultivation, as the main cash crop in Dano, is central to the local livelihood of the rural population [36].

The humid regions in southwestern Ghana are predominated by tubers such as cassava, yam, or cocoyam (also known as taro) and cash crops such as rubber, palm oil, or cocoa. Commercial production of rubber is the largest and most economically viable cultivar in the Western Region [37]. Despite an intensive expansion of agricultural land, food demand outpaces crop production. The key issues are a rapid population growth mixed with a changing urban diet [38].

2.2. Method

The developed methodology consists of a three-tiered framework to investigate food balance sheets that encompass (I) a data quality check as well as statistical analysis of climate and agricultural time series followed by (II) an estimation of annual population changes (III) to evaluate the food supply–demand nexus (Figure 2). To achieve our study objectives, we selected rainfall and temperature datasets, crop yield statistics, and census information supplied by local data providers and databases, as well as reports. Subsequently, the time series data were analyzed using various statistical approaches.

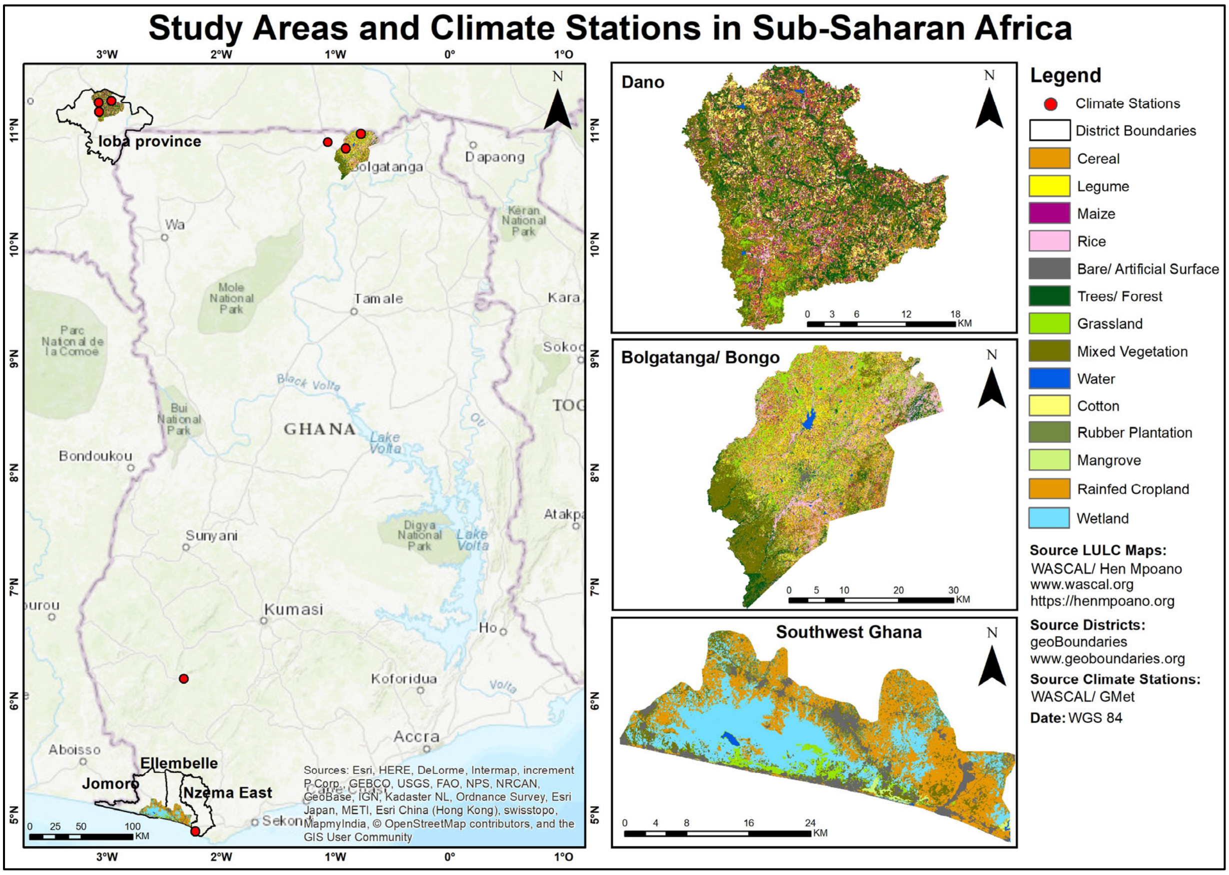

Figure 1. Study sites and climate stations.

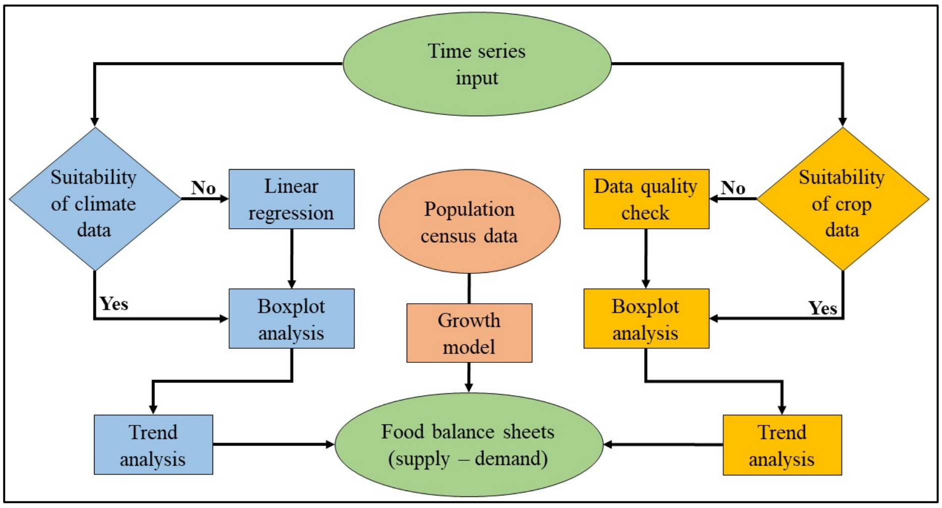

Figure 2. Analytical framework.

2.2.1. Climate Time Series

Meteorological datasets such as rainfall, minimum (Tmin) temperature, and maximum (Tmax) temperature were provided by WASCAL and the Ghana Meteorological Agency (GMet) with a temporal resolution from 5 min. to daily intervals (Table 1). The geographical locations of the used climate stations are shown in Figure 1. All data were aggregated by day and contain missing values due to interruptions in observations such as a breakage or malfunctions of instruments. Station measurements of rainfall, Tmin, and Tmax of the Dano catchment were adjusted from October 2012 to December 2018. Time series for the administrative units of Bolgatanga/Bongo covered a modified period between June 2014 and July 2019. Temperature datasets are only available as an average value of Tmin and Tmax (Table 1). Both climate stations, namely Aniabisi and Manyoro, comprised missing values for all variables with a majority of data gaps between 2014 and 2017. The time series of Aniabisi encompassed many suspect mean temperature data lower than 10 °C from May 2015 to June 2019. However, the daytime and nighttime temperature in the UER ranges between 26.10 °C and 41.10 °C as well as 13.25 °C and 29.10 °C [39]. Bongo Soe did not encompass any data gap.

Table 1. Climate time series.

<table>
<tr><th rowspan="2">Station</th><th rowspan="2">Rainfall [mm]</th><th colspan="3">Temperature [°C]</th></tr>
<tr><th>Min.</th><th>Max.</th><th>Mean</th></tr>
<tr><td colspan="5">Dano [October 2012–December 2018]</td></tr>
<tr><td>Bankandi</td><td>September 2012–December 2019</td><td colspan="2">September 2012–August 2018</td><td></td></tr>
<tr><td>Foundation</td><td colspan="3">September 2012–December 2018</td><td></td></tr>
<tr><td>Yabogane</td><td colspan="3">October 2012–December 2018</td><td></td></tr>
<tr><td colspan="5">Bolgatanga/Bongo [June 2014–July 2019]</td></tr>
<tr><td>Aniabisi</td><td>May 2014 to November 2019</td><td></td><td></td><td>May/2014 to November 2019</td></tr>
<tr><td>Bongo Soe</td><td>September 2012 to November 2019</td><td></td><td></td><td>September 2012 to November 2019</td></tr>
<tr><td>Manyoro</td><td>June 2014 to September 2019</td><td></td><td></td><td>June 2014 to September 2019</td></tr>
<tr><td colspan="5">Southwestern Ghana [January 1970–July 2015]</td></tr>
<tr><td>Axim</td><td>January 1960 to October 2016</td><td colspan="2">January 1960–July 2015</td><td></td></tr>
<tr><td>Sefwi-Bekwai</td><td>January 1964 to July 2016</td><td colspan="2">January 1964–August 2015</td><td></td></tr>
</table>

In total, GMet offered datasets of 14 climate stations for southwestern Ghana. We selected Axim and Sefwi-Bekwai as being most suitable because of their long-term coverage of climate variables with few data gaps. Time series of both weather stations involve similar missing values from the late 1970s to the mid-1980s and from 2010 to 2015, while incorrect values were detected for June 1976. This possibly indicates measurement failures of observations of precipitation, Tmin, and Tmax.

2.2.2. Agricultural Time Series and Food Consumption Data

Agricultural area and production and yield data were sourced from the Ministry of Food and Agriculture (MOFA) in Ghana between 1991/93 to 2016, while the Direction des Statistiques Agricoles/DGPSA/MAHRH in Burkina Faso provided primary information from 2001 to 2019 (Table 2). Time series for the Dano catchment were only available on the administrative level of the Ioba province and consisted of two different datasets from 2001 to 2006 and from 2009 to 2019 with a merging gap between 2007 and 2008. Missing yield values were identified for potato from 2002 to 2003 and sesame from 2011 to 2012. White and red sorghum exhibited a gap between 2001 and 2002 at the beginning of the time series.

Agricultural statistics for Bolgatanga/Bongo are provided for the majority of crops between the early 1990s and 2016. Only sweet potato, cowpea, and soya bean cover a shorter period from 2003 to 2016. A bigger data gap for maize exists between 2000 and 2004 in Bongo. The districts in southwestern Ghana revealed a similar time series collection from 1991 to 2016 with an exception for yam. Yield data of Nzema East and Ellembelle involve a missing value for plantain in 2009.

Table 2. Per capita food consumption and time series data (southwestern Ghana [40]; Bolgatanga/Bongo [41]; Ioba province [42]).

<table>
<tr><th rowspan="2">Crop</th><th colspan="2">Ioba Province</th><th colspan="2">Bolgatanga/Bongo</th><th colspan="2">Southwest Ghana</th></tr>
<tr><th>[kg/year]</th><th>Time Period</th><th>[kg/year]</th><th>Time Period</th><th>[kg/year]</th><th>Time Period</th></tr>
<tr><td>Maize</td><td rowspan="5">218</td><td rowspan="3">2001–2019</td><td>20</td><td rowspan="3">1991/93–2016</td><td>45</td><td>1991–2016</td></tr>
<tr><td>Rice (milled)</td><td>30</td><td>32</td><td></td></tr>
<tr><td>Millet</td><td>54</td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td>White Sorghum</td><td rowspan="2">2003–2019</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Red Sorghum</td></tr>
<tr><td>Sorghum</td><td></td><td></td><td>30</td><td>1991/93–2016</td></tr>
<tr><td>Cassava</td><td></td><td></td><td></td><td></td><td>152.9</td><td>1991–2016</td></tr>
<tr><td>Sweet Potato</td><td></td><td></td><td>10</td><td>2003–2016</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Potato</td><td rowspan="2">10</td><td rowspan="2">2001–2019</td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td>Yam</td><td>125</td><td>1998/99–2016</td></tr>
<tr><td>Cocoyam (taro)</td><td></td><td></td><td>40</td><td rowspan="2">1991–2016</td></tr>
<tr><td>Plantain</td><td></td><td></td><td>84.8</td></tr>
<tr><td>Groundnut (seed)</td><td rowspan="4">19</td><td rowspan="4">2001–2019</td><td rowspan="3">15</td><td>1991/93–2016</td><td></td><td></td></tr>
<tr><td>Cowpea</td><td rowspan="2">2003–2016</td><td></td><td></td></tr>
<tr><td>Soya Bean</td><td></td><td></td></tr>
<tr><td>Bambara Bean</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Cotton</td><td></td><td>2001–2019</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Sesame</td><td>16</td><td>2001–2019</td><td></td><td></td><td></td><td></td></tr>
</table>

Relevant consumption patterns were extracted from national reports (Table 2). Most prominent food crops of the Sudano-Guinea savannah are cereals. The prevalent type of food in southwest Ghana was determined to be tubers such as cassava or cocoyam.

2.2.3. Census Information

Population data were obtained from household census reports provided by the Ghana Statistical Service and the Ministère de l'Economie, des Finances et du Développement of Burkina Faso (Table 3). To be consistent with the agricultural statistics for the Dano catchment, we focused on the total population of the Ioba province where the population rate changed around 2.5% per year between both time steps [34,43]. The administrative units namely UER and the Western Region in Ghana estimated an annual population growth rate of 2% between 2010 and 2021 [35]. From 1960 to 2010, the UER recorded the lowest number of inhabitants due to outmigration activities [44]. Nowadays, dwellers of the UER primarily live in rural or scattered settlements. Conversely, the majority of citizens, around 52%, in the Western Region dwell in urban areas. A comparison of the District Analytical Reports 2010 and the Population Housing Census 2021 revealed for Bolgatanga a yearly population change of 3% while the number of residents in Bongo increased with an annual rate of around 3.3% [35,45,46]. In 2018, the eastern part of the Bolgatanga municipality unit was split off to establish the Bolgatanga East district. To maintain consistency, we retained census information from both parts as one administrative unit. The yearly population growth over the three districts in the Western Region ranges from 4.2% (Nzema East) to −1.6% (Jomoro) [35,47–49].

Table 3. Census data.

	Start Year	Census [No. of Residents]	End Year	Census [No. of Residents]
Ioba province	2006	192,321	2019	265,876
Bolgatanga (including Bolgatanga East)	2010	131,550	2021	178,688
Bongo		84,545		120,254
Nzema East		60,828		94,621
Ellembelle		87,501		120,893
Jomoro		150,107		126,576

2.2.4. Statistical Analysis

As a pre-processing step, we visually evaluated the suitability of all datasets with regard to missing values. A further screening of the climate time series comprised both the location of meteorological stations and the covered time periods. We used boxplots as an explanatory tool to understand the skewness, its data sub-structures, and the extremes of input time series. Corresponding to [50], values outside the range of the Tukey's method of 1.5-times the interquartile range (IQR) are considered as outliers. Crop yield extreme values were kept to avoid any bias from correction. Suspicious climate records were reconstructed from adjacent stations utilizing a linear regression technique. The coefficient of determination (R^2), as a validation criterion, helped to understand the relationship between two datasets to identify the most qualified time series to fill the gaps. To evaluate the reconstruction accuracy, the modified time series were compared to agro-climatological datasets of the NASA POWER project (https://power.larc.nasa.gov/; accessed on 7 May 2023) and existing literature [3,40,51].

To detect the presence of an upward or downward trend in the time series, we applied the non-parametric Mann–Kendall test. The method does not make any assumptions about the data distribution and the rank-based measure is not influenced by outliers [52]. The trend statistic (S) is derived as follows [53]:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k), sgn(x_j - x_k) = \begin{cases} +1 \; if \; (x_j - x_k) > 0 \\ 0 \; if \; (x_j - x_k) = 0 \\ -1 \; if \; (x_j - x_k) < 0 \end{cases} \quad (1)$$

where n is the length of the time series with the values x_j and x_k. The Kendall rank correlation assesses the monotony of a slope, varying between +1 indicating a rising trend and −1 representing a decreasing trend. The variance (Var) is computed to obtain the Z value by Equation (2):

$$Var(S) = \frac{n(n-1)\,(2n+5)}{18} \quad (2)$$

The standardized Z statistic is used to determine the trend with different significance levels at 90%, 95%, and 99% confidence. For calculating the Z value, we applied Equation (3):

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(S)}} \; if \; S > 0 \\ 0 \; if \; S = 0 \\ \frac{S+1}{\sqrt{var(S)}} \; if \; S < 0 \end{cases} \quad (3)$$

Additionally, we computed the trend magnitude by employing the Sen's estimator of slope [54]. The following formula was used to calculate the slope (Q_i) as a linear rate of change over time in original units per year:

$$Q_i = Median\left(\frac{X_j - X_k}{j - k}\right), (j > k) \quad (4)$$

where $x_1, x_2, x_3 \ldots x_j, x_k, \ldots x_n$ are the data statistics.

Subsequently, we balanced the food supply with local consumption patterns and census data to evaluate consumer surpluses or deficits. A simplistic growth model allows ascertainment of the yearly alteration in the population rate to project the food demand. We estimated the population rate at each time step by using a growth model:

$$P_{(year)} = P_{(0)} \times (1 + p/100)^n \quad (5)$$

where $P_{(year)}$ is the estimation of population in year x, $P_{(0)}$ represents the population size as the base, p is the growth rate, and n reflects the number of years [55].

3. Results

The analysis of climate and crop yield dynamics focuses on the rainy season to determine positive or negative changes on the supply side. Visualizing statistics as boxplots allows characterization of the quality of the time series including outlier or skew detection. There are three cases to define whether a dataset is left or right skewed related to the median and length of the whiskers. First, the median position is close to the bottom or top of the interquartile box and the whiskers are equal. Second, the median is placed at the center while one whisker is longer than the other one. However, the majority shows a combination of both cases. The median position within the IQR box is located where the lower quartile range (25th), represented by one color and the upper quartile range (75th) represented by another color, meet. The Mann–Kendall test and Sen's estimator of slope extend the boxplots by investigating changes over time. By comparing agricultural yield and population data, we were able to compute food balance sheets.

3.1. Climate

The R^2 coefficient, as a goodness-of-fit approach, was applied to select the most useful dataset for reconstructing missing climate information. The correlation among the rainfall time series ranged from 33% to 96% in Dano and Bolgatanga/Bongo. Conversely, the rainfall data in southwestern Ghana correlated less than 7%. Higher R^2 scores were computed for temperature values across the study sites. All datasets were resampled to a seasonal basis with six discrete time steps for Dano, four discrete time steps for Bolgatanga/Bongo, and forty-five discrete time steps for southwestern Ghana.

The boxplots of Dano show a high rainfall variability, ranging from 670.4 mm to 1082.6 mm with one outlier (Figure 3). The Bankandi time series reveals a compact rainfall distribution, while both remaining climate stations indicate greater oscillating rainfall rates. All temperature datasets of the Dano watershed encompassed a common gap that was fixed by a linear regression. The same approach was used to extend both temperature time series from September 2018 to December 2018 of the Bankandi station to ensure a similar temporal resolution. The temperature fluctuates between a minimum of 22.2 °C and a maximum of 35.2 °C, including two outliers for Tmax. The majority of time series illustrated right-skewed distributions with median positions close to the 25th percentile. This indicates either few heavy rainfall or few hot temperature events.

Bolgatanga/Bongo comprised two time series with outliers below the whiskers. The rainfall distribution with a mean value of 780.21 mm was mainly skewed left because of a large proportion of light rain events. Mean temperature boxplots demonstrated a high variability across all datasets ranging from 25.9 °C to 30.1 °C. Values of Aniabisi indicated a symmetric distribution, while both remaining datasets revealed a light-tailed skewness.

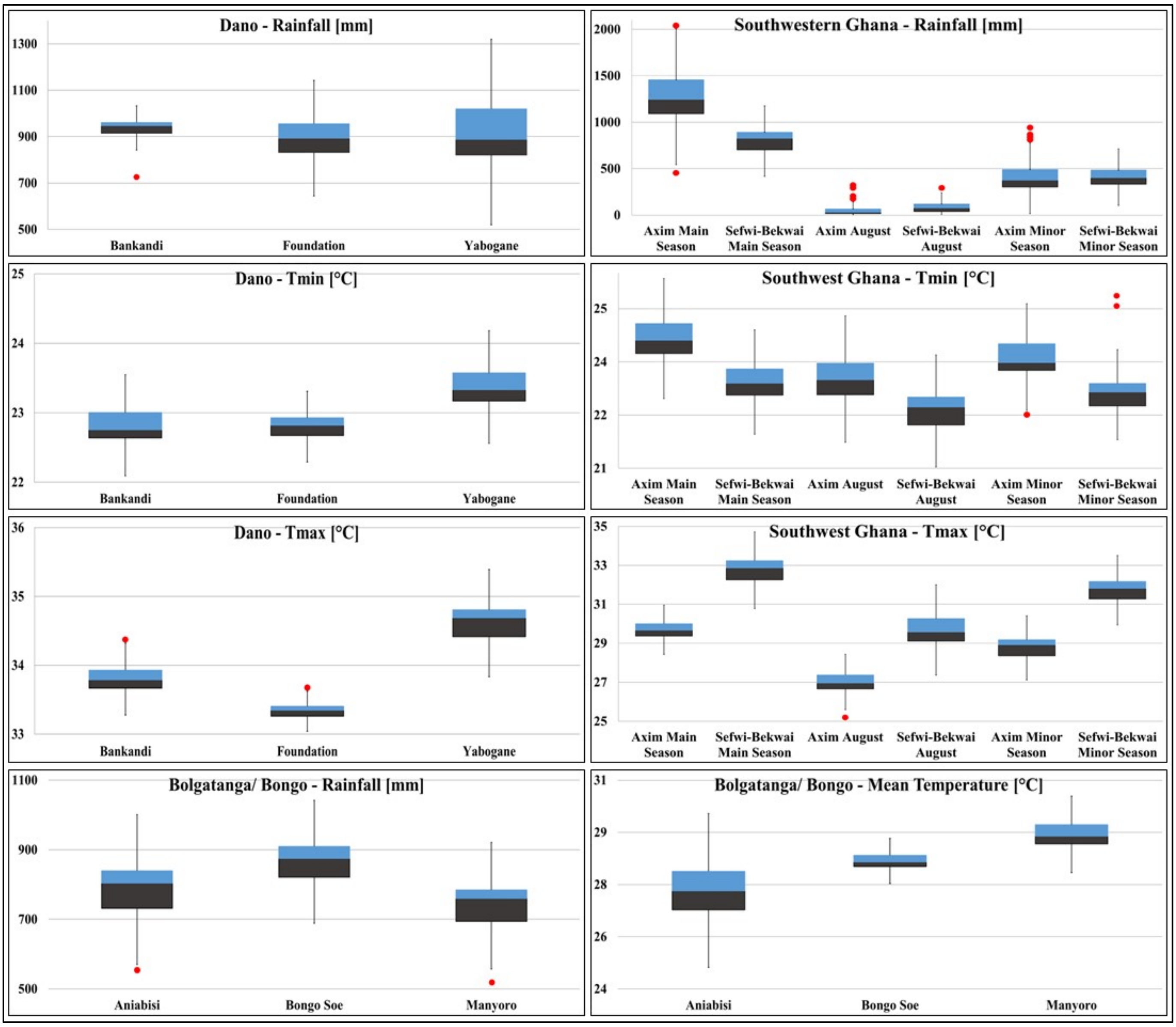

Figure 3. Boxplots of the seasonal climate analysis including outliers.

The time series of southwestern Ghana were divided into two wet seasons with a dryer August (Figure 3). The mean rainfall rate of the major wet season ranges from 554.6 mm to 1509.5 mm, while the minor rainy period oscillates between 175.3 mm and 723.4 mm. The August and minor rainy season comprised the bulk of outliers from the mid-1970s to early 2000s. Temperature time series varied from 21.6 °C to 32.3 °C for the entire rainy period. The majority of outliers were detected in August and during the minor wet season. Distributions of nearly all climate variables showed a right skewness with a tendency of the median location towards the bottom of the IQR box.

Table 4 presents an overview of the Mann–Kendall trend analysis at various confidence intervals and the Sen slope results. Rainfall statistics of Dano depict an insignificant and mostly downward directed tendency with a negative slope magnitude from −5.80 mm to −6.60 mm. Both stations Bankandi and Yabogane reveal a rising trend of Tmin, while the time series of Foundation does not include any trend direction. Tmax indicates either a growing or falling tendency. Only Yabogane demonstrates a substantial increase of both temperature time series of 0.14 °C.

Table 4. Climate trends (no significance: −; 0.10: +; 0.05: ++; 0.01: +++; Sen slope of rainfall in mm and temperature in °C).

<table>
<tr><th rowspan="2">Station Name</th><th rowspan="2">Rainfall</th><th>Min. Temperature</th><th>Max. Temperature</th></tr>
<tr><th colspan="2">Mean Temperature</th></tr>
<tr><td>Bankandi</td><td>Decreasing
− | −6.60</td><td>Increasing/
− | 0.02</td><td>Decreasing/
− | −0.06</td></tr>
<tr><td>Foundation</td><td>Increasing
− | 38.79</td><td>No Trend/
0.02</td><td>Decreasing/
− | −0.06</td></tr>
<tr><td>Yabogane</td><td>Decreasing
− | −5.80</td><td>Increasing/
− | 0.14</td><td>Increasing/
− | 0.14</td></tr>
<tr><td>Aniabisi</td><td>Increasing
− | 68.99</td><td colspan="2">Decreasing/
− | −0.94</td></tr>
<tr><td>Bongo Soe</td><td>No Trend
−4.47</td><td colspan="2">Decreasing/
+ | −0.26</td></tr>
<tr><td>Manyoro</td><td>Increasing
− | 21.08</td><td colspan="2">Decreasing/
− | −0.45</td></tr>
<tr><td>Axim (main season)</td><td>Decreasing
− | −2.55</td><td>Increasing
+++ | 0.03</td><td>Increasing
+++ | 0.02</td></tr>
<tr><td>Axim (August)</td><td>Decreasing
− | −0.11</td><td>Increasing
+++ | 0.02</td><td>Increasing
+++ | 0.02</td></tr>
<tr><td>Axim (minor season)</td><td>Increasing
− | 3.34</td><td>Increasing
+++ | 0.03</td><td>Increasing
+++ | 0.02</td></tr>
<tr><td>Sefwi-Bekwai (main season)</td><td>Increasing
− | 0.02</td><td>Increasing
+++ | 0.02</td><td>Increasing
+++ | 0.04</td></tr>
<tr><td>Sefwi-Bekwai (August)</td><td>Decreasing
− | −0.45</td><td>Increasing
+++ | 0.02</td><td>Increasing
+++ | 0.03</td></tr>
<tr><td>Sefwi-Bekwai (minor season)</td><td>Increasing
− | 0.21</td><td>Increasing
+++ | 0.02</td><td>Increasing
+++ | 0.04</td></tr>
</table>

The majority of climatic trends in Bolgatanga/Bongo are insignificant over time. An increasing rainfall trend exists for both datasets of Aniabisi and Manyoro with an exception for Bongo Soe. Aniabisi indicates the highest median Sen slope of 68.99 mm. The mean temperature declined at all stations, while only the data series of Bongo Soe exhibits a decreasing trend at a confidence level of 10%. The results show that the magnitude of the Sen slope fluctuates between −0.26 °C and −0.94 °C.

The rainfall regime in the Western Region oscillates between insignificant upward and downward trends with a slope magnitude range from −2.55 mm to 3.34 mm. The results show a strong increase of Tmin and Tmax at a confidence level of 1%. Over the entire rainy season, the Sen slope lies between 0.02 °C and 0.04 °C.

3.2. Crop Yield

Yield, production and area statistics presented a diverse agricultural pattern with much irregular data information. Biased production or area values did not often correspond to yield scores and vice versa. In addition to Tukey's boxplot rule, we focused on unreasonable production and area changes over time to pinpoint possible yield outliers. These yield values were masked as missing data and are represented as red dots in Figure 4. The remaining black dots were detected by using Tukey's outlier method. To avoid any distortion from outlier correction, we kept these suspicious values within the yield analysis.

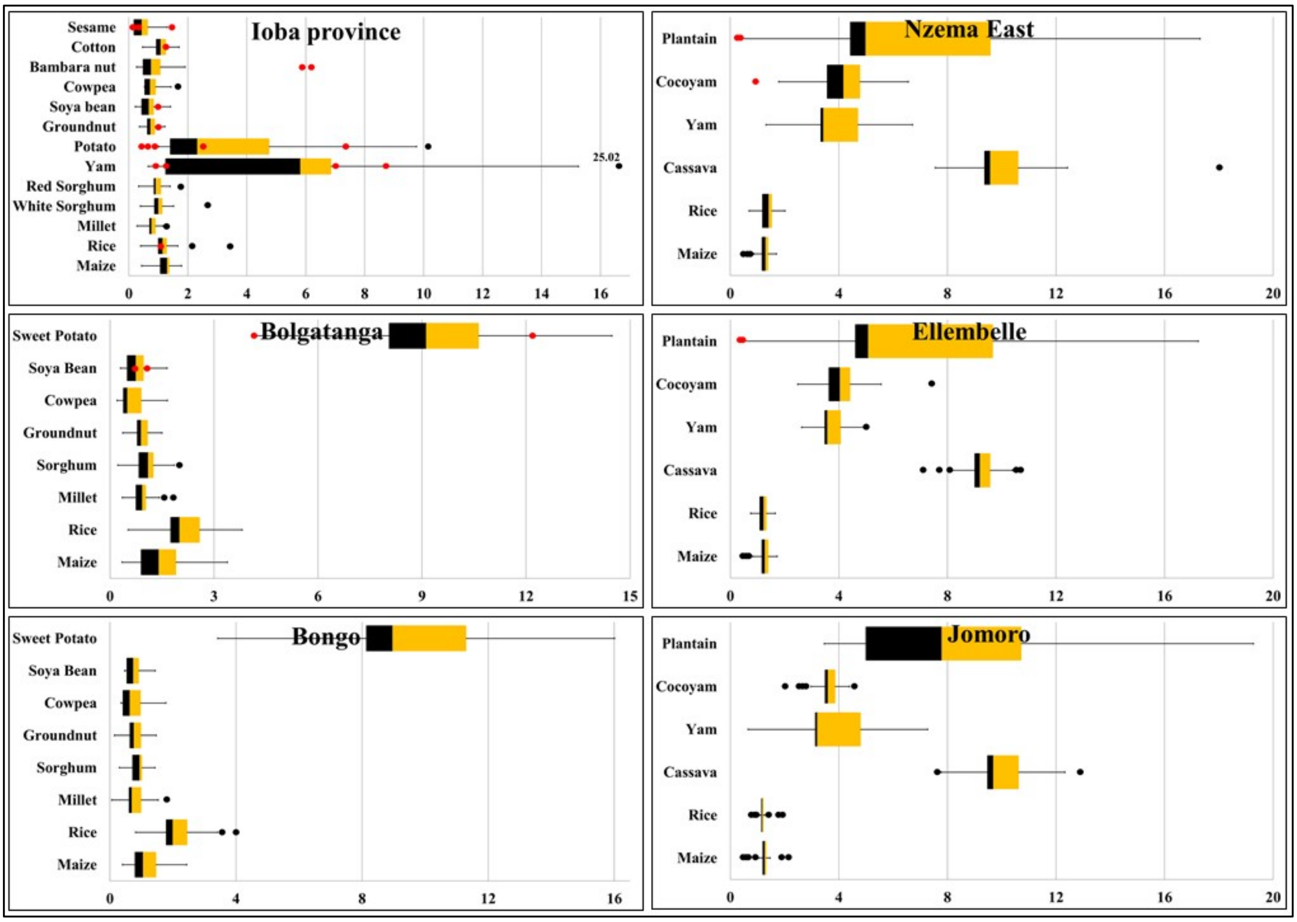

Figure 4. Crop yield boxplots (red dots: excluded from the analysis; black dots: suspicious outliers detected by Tukey's approach).

The Ioba province indicates yield statistics for cereals, legumes, cotton, and sesame between 0.08 ton/ha and 3.62 ton/ha, excluding extreme values (Figure 4). The majority of biased information was identified from 2005 to 2006 and in 2019. With regard to cereal data, maize and rice have the highest average yield, ranging from 1.24 ton/ha to 1.32 ton/ha. The mean yield of legumes oscillates between 0.66 ton/ha and around 0.76 ton/ha, where cowpea reveals the greatest value span. Root crops demonstrate a large yield dispersion with average values of 6.40 ton/ha for yam and 4.09 ton/ha for potato. Cotton yield lies between 0.66 ton/ha and 1.47 ton/ha, while sesame performs from 0.08 ton/ha to 0.79 ton/ha. A right-skewed distribution is shown for the bulk of crops that indicates a growing yield over time. Yam and maize exhibit a fluctuating production with a median position close to the top of the interquartile box.

Cereal time series illustrate for Bolgatanga/Bongo a high yield variation, where rice and maize range from 0.34 ton/ha to 4 ton/ha. Tukey's extreme value analysis determines unreliable information for rice, millet, and sorghum (Figure 4). Both research sites point out analogical yield statistics for legumes, ranging from 0.47 ton/ha to 1.43 ton/ha for groundnuts, from 0.2 ton/ha to 1.2 ton/ha for cowpea and from 0.3 ton/ha to 1.3 ton/ha for soya bean. Sweet potato, as an important root crop in the UER, shows lower yields in Bolgatanga compared to Bongo. An asymmetric distribution is given for almost all crops that signal a tendency of a right skewness. The equal length of the boxplot whiskers with a median position close to the first percentile underpins the findings for rice, millet, groundnut, and sweet potato. The sharp right skewed distribution with long tails for cowpea and soya bean indicates a rapid yield growth over a short-term period.

The agricultural pattern in Nzema East, Ellembelle, and Jomoro is mainly characterized by cereals, tubers, and plantain. Mean maize yield values vary over all three districts from

1.23 ton/ha to 1.25 ton/ha, while rice yield fluctuates between 1.19 ton/ha and 1.35 ton/ha. Tukey's boxplot method detected common outliers for maize from 1991 to 1993 for the selected datasets. Cereal boxplots across all districts represent a similar yield tendency based on the median location close to the middle of the IQR box with equal tails. Cassava, as the main root crop, illustrates a close yield range from 9.28 ton/ha to 10.06 ton/ha within the administrative regions. The remaining tubers, yam and cocoyam, depict a similar oscillating yield between 3.79 ton/ha and 4.31 ton/ha. Cassava and yam are mainly right-skewed with equal whiskers and a median break at the IQR bottom. All three datasets of plantain show an analogical characteristic where the first period between 1991 and 2003 signaled lower yields between 3.21 ton/ha to 5.25 ton/ha followed by a sharp increase ranging from 4.71 ton/ha to 13.43 ton/ha. Plantain exhibits for both datasets of Nzema East and Ellembelle a right-skewed distribution that confirms a rising yield over time.

Most crops in the Ioba province illustrate an increasing yield at varying confidence intervals (Table 5). Few yield time series grow at a significant level, for example red sorghum at the 1% level, cotton and maize at the 10% level. The Sen slope analysis of cereals reveals a high increasing yield value of 0.09 ton/ha for red sorghum and maize with 0.03 ton/ha. Over the same period, only yam decreases significantly at a 5% confidence level and demonstrates an essential yield loss of 0.61 ton/ha.

Bolgatanga/Bongo experience a great crop yield in both regions for maize at the 1% level, closely followed by rice and sorghum. Both administrative units indicate a strong rising yield of maize, ranging from 0.05 to 0.06 ton/ha. Bolgatanga exhibits a significant downward tendency for sweet potato and a Sen slope of −0.39 ton/ha. In Bongo, a significant upward trend is given for cowpea and soya bean at a 1% confidence level while all other crops show a stagnation yield pattern.

Table 5. Crop trends (no significance: −; 0.10: +; 0.05: ++; 0.01: +++; Sen slope in ton/ha).

Crop	Nzema East	Ellembelle	Jomoro	Bolgatanga	Bongo	Dano
Maize	Increasing ++ | 0.01	Increasing − | 0.01	Increasing + | 0.01	Increasing +++ | 0.05	Increasing +++ | 0.06	Increasing + | 0.03
Rice	Increasing − | 0.00	Increasing − | 0.00	Decreasing − | 0.00	Increasing − | 0.02	Increasing + | 0.04	Increasing − | 0.02
Millet				Increasing − | 0.00	Decreasing − | −0.01	Increasing − | 0.01
White Sorghum						Increasing − | 0.02
Red Sorghum						Increasing +++ | 0.09
Sorghum				Increasing + | 0.01	Increasing − | 0.01	
Cassava	Increasing +++ | 0.09	Increasing +++ | 0.06	Increasing +++ | 0.12			
Sweet Potato				Decreasing + | −0.39	Decreasing − | −0.22	
Potato						Increasing − | 0.38
Yam	Increasing − | 0.05	Increasing − | 0.02	Increasing +++ | 0.12			Decreasing ++ | −0.61
Cocoyam	Increasing +++ | 0.07	Increasing +++ | 0.04	Increasing − | 0.01			
Plantain	Increasing +++ | 0.30	Increasing +++ | 0.06	Increasing +++ | 0.29			

Table 5. *Cont.*

Crop	Nzema East	Ellembelle	Jomoro	Bolgatanga	Bongo	Dano
Groundnut				Increasing − ∣ 0.00	Decreasing − ∣ 0.00	Increasing − ∣ 0.01
Cowpea				Decreasing − ∣ −0.02	Increasing +++ ∣ 0.06	Increasing − ∣ 0.02
Soya Bean				Decreasing − ∣ −0.02	Increasing ++ ∣ 0.04	Increasing − ∣ 0.02
Cotton						Increasing + ∣ 0.02
Sesame						Increasing − ∣ 0.07
Bambara Bean						Increasing − ∣ 0.03

The districts located in southwestern Ghana indicate an increasing yield trend for almost all crops with an exception for rice in Jomoro. Cassava and plantain show a significant upward trend at a 1% confidence level and a Sen slope between 0.06 ton/ha to 0.12 ton/ha as well as 0.06 ton/ha to 0.30 ton/ha, respectively.

3.3. Food Balance Sheets

The analysis of food balance sheets was based on a comparison of agricultural production to census data. An unpublished report by [41] recommended taking into account a post-harvest loss of 20% for rice and 30% for all remaining crops. Thus, we decreased the yield statistics according to the supposed post-harvest loss values to quantify the net production. For example, indigenous storage facilities such as mud silos, barns, or drums are often used for storing grain or fodder. However, such storages are inefficient to protect crop products from biological, physical, or environmental hazards [56]. Subsequently, the yearly projected population growth was multiplied by the per capita consumption to project the demand. The mean values of both net production and estimated consumption were compared to identify a food surplus or deficit (Table 6). A more detailed overview of food supply and demand is provided in Figure 5. Cash crops such as cotton or sesame were excluded from the food balance analysis.

The aggregated food balance sheet of the Ioba province displays a surplus of 4113.3 ton. As shown in Figure 5, cereals and legumes indicate for almost all years a surplus. Tubers reveal permanently negative values over the whole period.

The overall food balance sheet of Bolgatanga demonstrates a surplus of 221.2 ton. While cereals and legumes indicate a strong deficit for the period between 2014 and 2017, there was a high surplus of sweet potato for all these years. Maize, millet, and sorghum represent a massive food shortage for the majority of crop years. On the other hand, almost all crop years exhibit positive rice values. Cowpea and soya bean show a consumption deficit compared to a huge groundnut surplus. A similar diet pattern is given for Bongo with an overproduction of 4846.77 ton due to a giant surplus of sweet potato. A food gap exists for maize or millet for the whole period and sorghum exhibits a deficit from 2015 to 2017. Conversely, a surplus of rice subsists for all years. Food consumption compared to crop yield is mainly negative for cowpea and soya bean, whereas groundnut indicates a vast surplus.

Table 6. Food balance sheets of rain-fed crops.

Crops	Total Production [ton]	Net Production [ton]	Per Capita Consumption [kg/year]	Estimated Consumption [ton]	Surplus/Deficit [ton]
Ioba province [2009–2020] ∣ ∑ 4113.3 ton					
Cereals	19,576.8	13,703.76	218	10,704.64	2999.12
Legumes	5619.41	3933.59	19	1228.79	2704.80
Tubers	95.19	66.63	10	1657.25	−1590.62
Bolgatanga [2011–2017] ∣ ∑ 221.2 ton					
Cereals	5321.25	3937.79	134	4968.70	−1030.91
Legumes	2637.14	1846	45	2224.79	−378.79
Sweet Potato	4448.71	3114.10	10	1483.20	1630.90
Bongo [2011–2017] ∣ ∑ 4846.77 ton					
Cereals	3966.16	2961.56	134	3231.84	−270.28
Legumes	2015.67	1410.97	45	1447.09	−36.12
Sweet Potato	8739.86	6117.90	10	964.73	5153.17
Nzema East [2011–2017] ∣ ∑ −193.33 ton					
Cereals	1086.44	779.42	77	2770.16	−1990.73
Tubers	19,610.77	13,727.54	317.90	7878.99	5848.55
Plantain	2929.12	2050.39	84.80	6101.54	−4051.15
Ellembelle [2011–2017] ∣ ∑ −13,617.47 ton					
Cereals	839.58	630.39	77	3798.23	−3167.84
Tubers	10,209.12	7146.38	317.90	10,454.18	−3307.79
Plantain	1748.76	1224.13	84.80	8365.97	−7141.84
Jomoro [2011–2017] ∣ ∑ −16,188.82 ton					
Cereals	1224.57	924.69	77	5420.86	−4496.17
Tubers	18,171.64	12,720.15	317.90	14,920.27	−2200.12
Plantain	3496.34	2447.44	84.80	11,939.97	−9492.53

All administrative areas in the Western Region of Ghana exhibit food insecurity with a common diet pattern over time. The grouped deficit of Nzema East amounts to −193.33 ton which represents the lowest value. Both neighboring districts demonstrate a deficit of −13,617.47 ton in Ellembelle and −16,188.82 ton in Jomoro. Maize, rice, and plantain depict a lack of consistent access to enough food from 2011 to 2017 at all sites. With respect to tubers, the results indicate inconsistent food balance sheets across the regions. Root crops of Nzema East illustrate a positive relationship between consumption and agricultural yield with a shortage in 2012. Conversely, the adjacent districts Ellembelle and Jomoro present a deficit. Only cassava indicates an excellent agri-food situation over the analyzed period for all areas. Yam and cocoyam represent an imbalance between demand and food production.

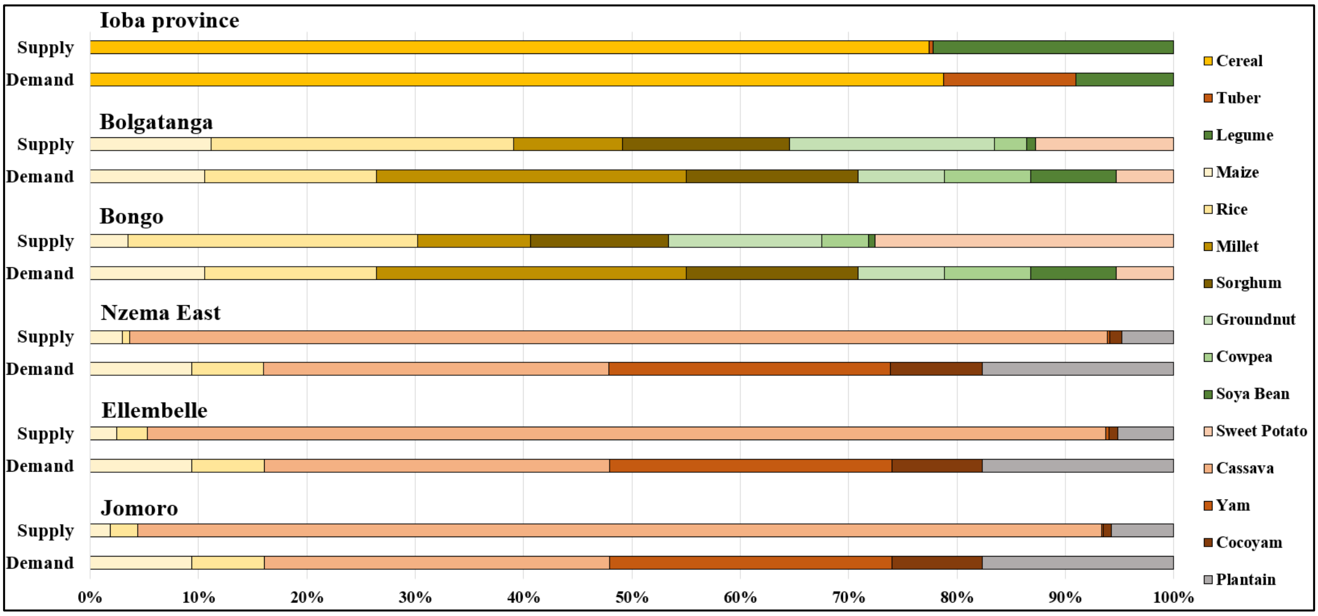

Figure 5. Food supply and demand.

4. Discussion

This section presents a discussion on the magnitude and consequences of climate variation as well as socio-economic challenges on agriculture. Evidence suggests that analyzed rainfall and temperature changes of recent years are affecting food supply. We focus on crops with significant trends to understand temporal yield changes. To extend this, fluctuations in crop production are related to agricultural policies or subsidy programs and how this will support a positive food balance.

4.1. Climate Variability

Climate results of the Sudano-Guinean savannah revealed a growing variability over the rainy periods. Rainfall time series demonstrated almost insignificant upward or downward trends. The rainfall rate of the Dano catchment agrees with the findings by [57], while [58] identified a slight increase during the recent years. The latter study characterized three rainfall clusters in Burkina Faso starting with the first cycle in 1970 to 1990. This period is marked by various years of droughts in 1982, 1983, and 1987. The following phase is classified as an intermediate circle ranging from dry conditions to wet years until 2008. The third trend from 2008 to 2013 is determined by a return to more positive rainfall patterns. However, the start and end of the rainy season are impacted by the movement of the inter-tropical front that results in a shift of the wet period towards the north [59]. In this regard, [60] reported that the annual temperatures of the coolest and hottest days rose in Burkina Faso from 1950 to 2013. Mean values of Tmin with 22.9 °C and Tmax with 33.96 °C exhibited a non-significant and contrary tendency in Dano. The majority of values of the Tmin time series increased, while the Tmax datasets showed a declining trend.

With a focus on Bolgatanga/Bongo, the rainfall rate is lower than the findings by [61], who reported a yearly precipitation of 901.9 mm with similar trend results. In addition, the warming of the North Atlantic Ocean has causes a rising oscillation in the amount of rainfall over recent years [62]. The mean temperature of Bolgatanga/Bongo decreased at all stations and only the Bongo Soe time series exhibited a significant downtrend at a confidence level of 10%. This result is in line with the outcomes by [61], who identified a slightly decreasing trend for the neighboring Bawku municipality. Zooming out to the regional climate system leads to a diverse view where natural processes such as solar variability, waterbodies, vegetation, and fast-moving squall lines with larger convective complexes determine the local temperature of Dano as well as Bolgatanga/Bongo [63].

The climate regime in southwest Ghana indicated a fluctuating and insignificant rainfall trend. Results on rainfall mean values of the major wet season of 1028.64 mm and the minor rainy period of 413.44 mm are inconsistent with the outcomes by [64]. Findings of their study detected a precipitation range from 2074.5 mm to 2863.8 mm during the main spell, while observations of the minor season ranged between 650.5 mm and 1446.8 mm. The reasons can be linked to non-linear interactions with factors such as urban sprawl, distance to ocean, or atmospheric drivers. According to [65], the variability of the major season is strongly affected by atmospheric moisture that may result in upward humidity trends over the minor period. A recent study by [66] determined a growing rainfall tendency during the minor cycle that agrees with the Mann–Kendall trend results. Also, the greening of the rain forest causes higher surface moisture which most likely enhances the amount of precipitation. This temperature analysis implied a strong rising mean Tmin of 23.05 °C and Tmax of 29.92 °C throughout the inter-seasonal periods at a confidence level of 1%. The results are in line with the statistical findings by [64] who detected a yearly temperature range from 26.9 °C to 27.9 °C.

4.2. Effects on Agricultural Yield

The investigation of rain-fed agriculture indicated a clear dominance of maize and rice across all study sites. Both crops have been extended from southern regions in West Africa to the Sudanian zone because of breeding efforts that meet yield responses to the low availability of fertilizer [67,68]. Despite similar farming patterns in the Sudano-Guinean savannah, yield trends vary greatly between the countries. A study by [69] highlighted that climate variabilities associated with low soil fertility, floods, and management practices have serious impacts on agricultural production. These driving forces can be connected to significant growing yields of red sorghum, maize, and cotton, while only yam declined at a confidence level of 5% in the Ioba province. According to [70], yam requires precipitation greater than 800 mm and high soil fertility to maintain productivity. The calculated mean yield of 6.4 ton/ha for yam was not consistent with a recent study by [71] who identified a range from 6.75 ton/ha to 26.8 ton/ha for northwestern Burkina Faso. Thus, red sorghum and/or maize represent an alternative to nutrient-poor soils or heavy-drought events in the Sudano-Guinea area [55]. The priority of farmers to cultivate red sorghum is intended for commercialization and probably accounts for the strong upward yield tendency. In the case of maize, the yield trend rose significantly, while intensification practices are mainly limited by the availability of farm inputs or subsidy programs [33]. At the same time, maize farmers who also grow cotton are eligible to receive subsidized fertilizers from their cooperatives. A national fertilizer program was initiated after the crop price shock in 2008 and has led to a great expansion of maize–cotton rotation systems [72]. Cotton, as the main cash crop, increased remarkably at a 10% confidence level which conforms with the findings of [73]. The study reported that cotton production increased nearly fourfold from 1995 to 2005 and forms one of the economic backbones in Burkina Faso.

The analyzed maize yields of Bolgatanga/Bongo conform with the findings of [74], who reported a range from 0.8 ton/ha (without fertilizer) to 1.8 ton/ha (with fertilizer). To compensate a low crop yield, [75] suggested that a growing application of nitrogen would boost the maize production up to 3.6 ton/ha. Both yield trends of sorghum in Bolgatanga and rice in Bongo rose slightly significantly. Ref. [76] found out that many farmers in northern Ghana prefer to cultivate sorghum due to lower risks of crop failures in the case of droughts or insufficient soil fertility. Although rice yield variability is mainly related to climate adverse conditions, harvested areas have been widely extended in Bolgatanga/Bongo. The significant trends of cowpea, with an average of 0.71 ton/ha and soya bean with a mean of 0.78 ton/ha recorded in Bongo, remained low compared to a potential yield over 2 ton/ha for cowpea [77] or an estimated production of 2.5 ton/ha for soya bean [78]. Intercropping legumes with sorghum, millet, or maize raise soil fertility by fixing atmospheric nitrogen which conserves nutrients for higher productivity of cereals [79]. While sorghum, millet, and cowpea are well-known as climate-resilient crops in the Sudano-Sahelian savannah, tubers, such as sweet potato, attain high prominence in the Guinean zone because of their short-term growth cycle [80]. However, our findings indicated a decreasing yield trend for sweet potato in Bolgatanga. A study by [81] classified various socio-economic impacts, such as a lack of access to markets or a high perishability rate of sweet potato, which limit the growers' ability to expand production.

Significant yield trends of maize, cassava, cocoyam, and plantain are almost similar across the districts in southwestern Ghana. Farmers in this site enjoy the advantage that rainfed maize can be cultivated twice in a year. The growing periods follow the rainfall pattern with a major planting season from April to August, while the second cultivation phase starts in September and ends in December [82]. Yet, the mean maize yield of around 1.25 ton/ha remains low compared to other African countries such as South Africa with 4.9 ton/ha or Ethiopia with 4.2 ton/ha [83]. Results on cassava revealed a strong rising trend at a confidence level of 1% with a ranging yield from 9.28 ton/ha to 10.06 ton/ha in this region. This trend is mostly related to a massive expansion of cropland that fits with findings by [84] who identified an extensification of farming practices between 1990 and 2010. Many interventions have been made to improve the productivity by providing extension services to introduce new technologies, offer climate data, or other farming related information [85]. The further assessment of cocoyam revealed significant trends with mean yields from 4.21 ton/ha to 4.31 ton/ha in Ellembelle and Nzema East. These findings agree with a report by [86] where cocoyam ranges from 4 ton/ha to 6.5 ton/ha. However, the productivity per area is much lower compared to the high yield potential of up to 120 ton/ha in small areas in Zimbabwe [87]. In particular, proper water management and affordable farm inputs are key to maximizing crop outcomes. The yield trend of yam showed an analogical strong tendency of 3.75 ton/ha in Jomoro, while similar environmental and socio-economic impacts are associated with low yields. Moreover, plantain is often cultivated in cocoa farms or in combination with other crops such as cassava, cocoyam or yam [88]. All three districts classified a significant rising yield trend at a level of 1% that is congruent with the results of [89], who attributed growing yields to improved research and extension activities.

4.3. Demand and Food Production

The Ioba province produced a total surplus of 4113.3 ton that made it possible to cover the regional demand. The cereal and legume yield statistics indicated sufficient quantities, while tubers revealed a deficit. A report by [90] highlighted the rising consumption of maize and rice due to a changing urban diet. However, domestic cultivated rice is often not very competitive because of large household size or low incomes, steering consumers to commodities with the lowest price. Thus, rice imports will possibly increase as the growing population outpaces current production. The proportion of rice consumption covered by domestic farming declined from 70% in the mid-1990s to around 30% in the early years of the last decade [91]. It is projected that the population of Burkina Faso will reach 26 million by 2030 and approximately 41 million by 2050 [92]. Against this backdrop, millet and sorghum are known as crops for vulnerable households, while maize is consumed by the majority of people. Yet, the crop results revealed relatively small quantities for millet and white and red sorghum because the three staple crops are traditional subsistence cultivars. Legumes as companion crops with cereals play an essential role in the diets of locals. Cowpea, groundnuts, soya beans, and Bambara beans are grown for on-farm consumption, domestic marketing outside households, and for export to neighboring countries such as Ghana or the Ivory Coast [93]. On the other hand, consumption of tubers has increased even faster than agricultural production. Ref. [94] emphasized the importance of potato as a foodstuff, but the cultivar is still acknowledged as a minor crop.

All districts of both Ghanaian research sites demonstrated low cereal output which fails to respond to local demand. As in Burkina Faso, rice is mainly related to urban diets that account for about 76% of total consumption [95]. In this regard, Ghana depends largely on rice imports with shares remaining above 50% to stabilize domestic markets. To reduce the dependency on imports, the central government-initiated campaigns, such as the Fertilizer Subsidy Program or Block Farms Program with a key focus on raising farm productivity. These interventions have been rolled into the flagship initiative Planting for Food and Jobs to provide subsidized seeds and fertilizer for prioritized crops [96]. However, the productivity of the agricultural sector does not determine individual food consumption preferences. For example, per capita consumption of maize is highest in northern Ghana, while the same region contributes 20.7% to the national production. By contrast, southern Ghana is not traditionally a maize-growing area, yet its inhabitants claim 32% of demand. In conformity with MOFA-IFPRI Market Brief No. 1 [97], Bolgatanga/Bongo showed a lower cereal balance deficit compared to southwestern Ghana. The total surplus in Bolgatanga of 221.20 ton and Bongo of 4846.77 ton was achieved decisively by cultivating sweet potato. Despite declining yield trends, the production of sweet potato remained higher than the need. Reasons are related to socio-economic constraints such as lack of awareness, high perishability, or inclusion in daily diets [81]. In southwestern Ghana, the majority of tubers indicated negative root crop balances sheets with the exception of Nzema East. The massive surplus in the tuber food balance might result from historical land transitions to agriculture, while Ellembelle and Jomoro are more covered by forest reserves or protected natural areas. Cassava, yam, and cocoyam are primarily cultivated for home consumption to improve food security or as cash crops to generate income. The rising local and international demand for cassava allows the enhancement of marketing and export activities which increase the farmer's livelihood [98]. Ranked after cassava and yam, plantain is the third most valuable starchy staple with considerable socio-economic significance which creates jobs [97]. Yet, the marketing is often disturbed by a lack of value chains or limited communication between producers and urban consumption centers. Also, plantain is highly perishable and prone to post-harvest losses that affect both quality and quantity [89].

5. Conclusions

This study investigated food supply and demand as an interplay between climate change impacts, crop production, and population growth along three study sites from southwestern Burkina Faso to southwestern Ghana. The empirical analysis of rainfall and temperature time series demonstrated a high variability with an indication of few but heavy climate events. These results were backed by a trend test where the study sites in the Sudano-Guinean savannah mostly revealed an insignificant tendency for all climate variables. The research site in southwestern Ghana illustrated erratic downward and upward tendencies in rainfall changes while temperature patterns showed a strong increasing trend for all sub-seasons. Yield statistics of Dano and Bolgatanga/Bongo revealed a huge variability of significant crops. In particular, maize, rice, and sorghum were identified as essential crops. Towards southwestern Ghana, a strong yield growth was characterized for almost all tubers. Trends depicted a similar sharp growth in cassava, cocoyam, and plantain yield. It was found that the rising agricultural production did not result in a balanced supply and demand for all sites. Only the research site in Dano exhibited a positive food balance for primary cereal and legume crops while the tuber cultivation does not meet the regional demand. On the other hand, both study regions in Ghana represented a consumption pattern for cereals, legumes, or tubers that outpaces the recent on-farm supply. The prevailing evidence from the results suggests that climate variation as well as agricultural management practices determine food crop production. Many interventions were rolled out in both countries to provide subsidized seeds or fertilizer. However, bridging the supply and demand gap will remain an ongoing challenge that needs further policies in both countries in order to focus on a larger array of commodities, imports, and marketing of food products.

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