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Effect of climate variability on yields of selected staple food crops in northern Ghana

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ABSTRACT

Agriculture in Ghana is vulnerable to the adverse effects of climate variability. This poses a challenge to food security across the country. Despite this vulnerability, limited research has been conducted to understand the effect of climate variability on the yields of staple food crops in Ghana. This study assessed the effect of climate variability on the yields of selected staple food crops (millet, sorghum, rice, groundnut and maize). The study used the Mann-Kendall trend test and multiple regression analysis to assess how climate variability (in annual rainfall, onset, cessation, number of dry days and temperature) has affected the yields of selected food crops in five districts in northern Ghana (Bole, Nanton, Tolon, Kassena Nankana East and Wa) over a 21-year period (1995–2016). Results suggested a marginal decrease in annual rainfall ($p > 0.05$) and a significant increase in temperature ($p < 0.05$) over the period of study in the districts. Variability in the onset, cessation, length of rainy days and number of dry days was statistically significant from year to year, and also across the districts ($p < 0.05$). Results indicated substantial variability in the yields of the selected staple food crops. Temperature, number of dry days, onset, annual rainfall and cessation explained about 43%, 32%, 30%, 25% and 14%, respectively of the variations in the yields of groundnut, sorghum, millet, maize and rice. Our results generally suggest that the changing climate substantially affects food production in the study districts, highlighting the need for adaptations including the use of agricultural diversification and the greater use of drought tolerant varieties of these staple crops, as well as the continuing investment in crop breeding programmes to enhance drought tolerance.

1. Introduction

Climate variability poses a major challenge to the sustainability of agro-based livelihoods in sub-Saharan Africa [1], due in particular to the region's low adaptive capacity and weak institutional framework [2]. This threatens the livelihoods of many households across the region, with serious implications for the attainment of the Sustainable Development Goals (SDGs) particularly goals relating to poverty reduction [3].

Ghana has been identified to be one of the countries most vulnerable to the adverse impacts of climate variability [4,5]. This is because, agriculture which is an important sector of the country's economy and employing more than 70% of the work force is predominantly rain-fed [6]. An estimated 5% of Ghana's population are food insecure with an additional two million vulnerable to become food insecure [6] as the average yield of maize, rice, millet, sorghum and groundnut which are used to meet the basic food requirement of majority of the Ghanaian population has not increased. Hence, importation of commercial food and food aid have reached about 4.7% of food needs [6]. In northern Ghana, proportionately small rainfall variability can induce substantial effects on crop yield, due to limited adaptive capacity [4]. Northern Ghana has experienced severe climate-related events including droughts and floods which led to the destruction of crops and livestock resulting in famine [7]. Such extreme events, are predicted to increase in the future because of climate change [1].

Northern Ghana has encountered persistent economic stagnation resulting in rural-out relocation [7]. Also, farmers cannot access reliable and useable climate services and many of them find it difficult to

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understand the weather and climate forecast details and terminologies [8,9]. Despite the vulnerability of northern Ghana to climate variability, studies examining the impacts of climate change and variability on agricultural production in the region have been limited (see Amikuzuno and Donkoh [10]; Mabe et al. [11]; Ayumah [12]). For instance, Amikuzuno and Donkoh [10] suggested that inter-annual yields of maize, rice, millet, sorghum, groundnuts and yam have been affected by total amounts of rainfall while temperature variability had minimal effect on the yields of the selected food crops in northern Ghana. Mabe et al. [11] reported that the variations between minimum and maximum temperatures do not have significant effects on rice yield in northern Ghana. Furthermore, Ayumah [12] revealed that rainfall significantly explained variation in maize production while temperature was not significant in explaining the variation of rice, maize and millet production in Bawku Municipality in the Upper East Region of Ghana. These studies have largely focussed on the effect of annual rainfall and temperature on food crop production. However, evidence on the effects of rainfall onset, cessation of rains, number of dry days and length of rainy days on the yield of food crops is lacking. These variables have been found to be critical correlates of food crop production in many countries such as Kenya and Niger [13].

The current study, thus, aims to fill this knowledge gap by providing an in-depth understanding of the effect of climate variability (in annual rainfall, onset, cessation, number of dry days and temperature) on the yields of selected staple food crops in selected districts of northern Ghana, where climate variability threatens food security. The study answers the following research questions: (i) what is the extent of rainfall and temperature changes in the five selected districts (Bole, Nanton, Tolon, Kassena Nankana East, and Wa) in northern Ghana for the period 1988–2016? (ii) what is the trend of yield of millet, sorghum, rice, groundnut and maize in the study districts for the period 1995–2016? and, (iii) does climate variability affect the yields of the selected staple food crops in the study districts in northern Ghana? It was hypothesized that climatic variables would exert significant positive effects on staple food crops in northern Ghana.

2. Materials and methods

2.1. Description of study areas

Northern Ghana is characterized by unimodal patterns of rainfall and this makes it difficult for farmers to achieve adequate yield levels of crops to meet the consumption demand of the region and the country in general [10,14]. It is in this light that, northern Ghana was selected for this study.

Five districts from each of the three regions in northern Ghana (Northern region, Upper East region and Upper West region) were purposively selected for the study because of their importance for food crop production in their respective regions, and their vulnerability to climate change [4,15–17]. These districts, namely: Bole, Nanton, Tolon, Kassena Nankana East and Wa are shown in Fig. 1, with their characteristics presented in Table 1.

2.2. Data collection

Monthly rainfall and temperature data for Bole, Tolon, Nanton, Kassena Nankana East and Wa districts were collected from four Ghana Meteorological Agency (GMet) stations across northern Ghana covering the period of 1988–2016 (Fig. 1). The monthly rainfall and temperature data obtained were analysed for mean annual rainfall and temperature. Daily rainfall data for the study districts were also collected and allowed even more precise dynamics to be analysed. For instance, the rainfall onset, number of dry days and cessation trends were also analysed to determine their influence on crop yields [18–20]. The choice of the criterion used in determining the rainfall onset and cessation was guided by the concept of Marteau et al. [21], Marteau et al. [22] and Ngetich

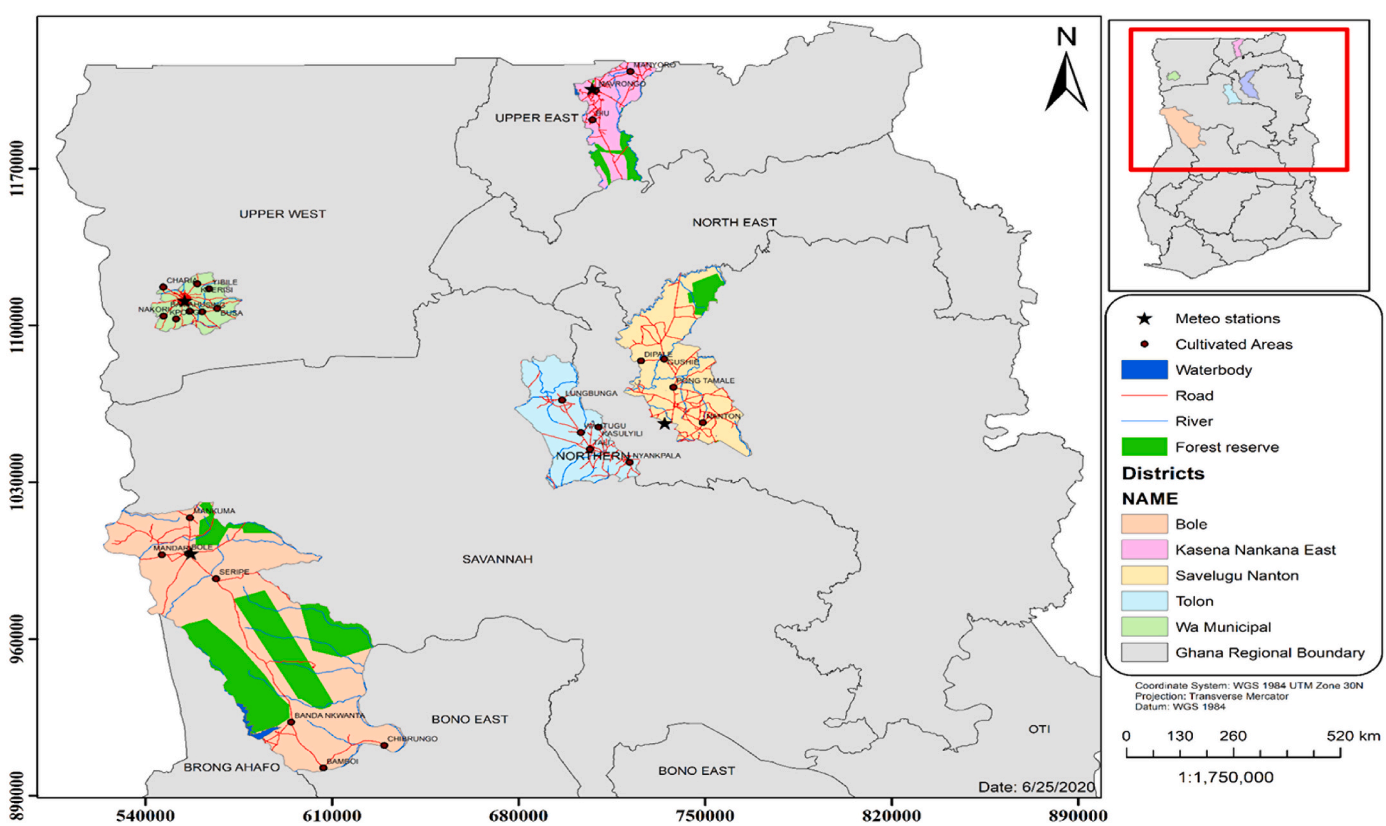

Fig. 1. Map of northern Ghana showing the study districts, weather stations and cultivated areas of staple food crops.

Table 1
Description of the selected study districts in northern Ghana.

Features	Districts: Bole	Nanton	Tolon	Kassena – Nankana East	Wa
Position in northern Ghana	Extreme western part of Northern Region	Northern Region	Northern Region	Upper East Region	Upper West Region
Location coordinates	Latitudes 8′ 10.5 and 09′N	Latitudes 9.8115° N and Longitude 0.8294° W	Latitude 9° 15' and 10°0 02′ N	Latitude 11°10′ and 10°3′ N Longitude 10°1′ W	Latitude 1°40′ to 2°45′N Longitudes 9°32′ to 10°20′W
	Longitude 1.50E′ and 2.45 W		Longitudes 0° 53'and 1° 25' W		
Area Total	6169.2 km^2	1790 km^2	2389 km^2	1657 km^2	579.86 km^2
Climatic conditions	Average temperatures: 26 °C – 27 °C	Average annual rainfall of 600 mm. The annual rainfall pattern erratic High temperatures average: 34 °C.	Mean annual rainfall: 950 mm–1200 mm.	Average annual rainfall: 950 mm.	Rainfall pattern: Irregular and unreliable.
	Annual mean rainfall: 1000–1200 mm Relatively high annual evapotranspiration: 1600–1650 mm.		Day temperatures: 33 °C–39 °C Mean night temperature: 20 °C–26 °C.	Day temperatures are high recording 42 °C Night temperatures could be as low as 18 °C	Average annual rainfall: 879 mm. Daytime temperatures often reach 40 °C.
Agriculture	61.6% of households in the district are engaged in agriculture. 95% of households in the district are involved in crop farming.	89.3% of households in the district are engaged in agriculture. 97.0% are involved in crop farming.	92.4% of households in the district are engaged in agriculture. Major crops: maize, millet, rice, yam, groundnut, sorghum, soya bean and cowpea.	Agriculture is the dominant economic activity in the municipality. Major crops: millet, sorghum, rice, groundnuts, leafy vegetables, cowpea, bambara beans, okro, cotton, tomatoes and onions.	Most of the farmers are engaged in peasant farming. Main crops: millet, sorghum, maize, rice, cowpea and groundnut cultivated on subsistence basis.
	Major crops: maize, millet, sorghum, rice, groundnut and cowpea	Major crops: maize, rice, millet, sorghum etc.			
Economic activity status	About 74.7% of the population aged 15 years and older are economically active.	About 77.6% of the population 15 years and older are economically active.	About 80.5% of the population aged 15 years and older are economically active.	About 70.2% of the populations aged 15 years and older are economically active.	About 54.8% of the population aged 15 years and older are economically active

Source: Ghana Statistical Service [15].

et al. [23]. The length of the rainy season was calculated as the difference between the day numbers of the determined cessation date and the determined onset date for that particular year [24,25].

One of the key agricultural threats especially during the growing season of a crop is the occurrence of dry spells [26–28]. Hence, we estimated the likelihood of the occurrence of the number of dry days of various lengths [27,28]. We defined "dry spell" as the period of five consecutive days of no recorded rainfall (daily rainfall = 0 mm with a threshold of 1 mm for a rainy day) [28]. Therefore, the total number of occurrences of five consecutive dry days across the years for the study districts were computed. The yield data of the selected staple food crops for the period 1995–2016 from the study districts were obtained from the Ghana's Ministry of Food and Agriculture offices in each district. Their yields data were estimated in metric ton per hectare (MT/ha). For a given crop and district, the average yield (in metric ton per hectare) corresponds to the ratio of the estimated harvest to the estimated planted area for the district. The cultivated areas of selected staple food crops in each district are also shown in Fig. 1.

2.3. Data quality control

One key problem with using long time-series record of the meteorological dataset is data gaps [29]. Thus, these data gaps had to be properly filled and quality-controlled to provide reliable, continuous and homogenous reference time series in which differences are only caused by weather and climate variability [29]. The normal ratio method following Young [30] was employed to generate the serially complete dataset. The method was represented as:

$$P_X = \frac{1}{m}\sum_{i=1}^{n}\left[\frac{N_x}{N_i}\right]P_i \tag{1}$$

where.

P_i = data at surroundings stations
N_x = normal monthly data at station x
N_i = normal monthly data at station i
m = number of surrounding stations

2.4. Trend analysis of climatic variables

Time series analysis was used to investigate the trend in annual rainfall, mean annual temperature, onset, cessation, length of rainy season and number of dry days for the period 1988–2016. Trend test was used to detect whether rainfall and temperature monotonically increased or decreased with time. The non-parametric Mann-Kendall (MK) test was used for trend analysis while Sen's slope estimator was used to calculate the magnitude of the trend [31,32]. Mann-Kendall trend test assumes no serial correlation or autocorrelation in the time series [33]. Only the trend component was used for analysis to avoid distortion due to irregularity in the data. Continuity correction was applied on ties that were detected in the data [34]. The variability in annual rainfall and temperature in each district was estimated using coefficient of variation. A two–way analysis of variance (ANOVA) was used to compare the means of onset, cessation, length of rainy days and number of dry days for the years and the districts, and where differences existed, Tukey's honestly significant difference test was performed to tease out the differences.

2.5. Trends and variation in the yield of selected food crops

The main food crops grown in the study districts are: maize, millet, rice, sorghum, cassava, yam, groundnut, cowpea, soya bean and sweet potato. However, for the purpose of this study, millet, sorghum, rice, groundnut and maize were selected. These crops are also used to meet the basic food requirement of majority of the Ghanaian population [6]. The coefficient of variation was calculated as a measure of the variability in the yields of the staple food crops. The variability in crop yields documented in countries found in SSA are highlighted by climatic and non-climatic factors, e.g., technological improvements or economic factors, unsustainable methods of agriculture and restricted access to adequate farm inputs including tractors [35–37]. However, due to data limitations, non-climatic factors were not included in this study.

2.6. Effect of climate variables on the yields of selected staple food crops

A multiple regression model was used to estimate the effect of the climate variables on the yields of the selected staple food crops over a 21-year period (1995–2016). This method has been used extensively in analysing the effect of climate variability on food production [38,39]. The correlation coefficient *(r)* was used to indicate how delicate the yields of the selected staple food crops are to climate variability. The significance level for this study was set at 0.05. The model was represented as:

$$Y = \beta_o + \beta_1 X_i + \beta_2 X_{ii} + \beta_3 X_{iii} + \beta_4 X_{iv} + \beta_5 X_v + \mathcal{E} \ldots\ldots\ldots\ldots \quad (2)$$

where $\boldsymbol{Y}$ = response variable which is the yield of the food crop; $\boldsymbol{\beta_o}$ = y intercept or the constant of the model; $\boldsymbol{\beta_1}$ = coefficient of $\boldsymbol{X_i}$; $\boldsymbol{X_i}$ = mean annual temperature (°C); $\boldsymbol{\beta_2}$ = coefficient of $\boldsymbol{X_{ii}}$; $\boldsymbol{X_{ii}}$ = annual rainfall (mm); $\boldsymbol{\beta_3}$ = coefficient of $\boldsymbol{X_{iii}}$; $\boldsymbol{X_{iii}}$ = rainfall onset (days); $\boldsymbol{\beta_4}$ = coefficient of $\boldsymbol{X_{iv}}$; $\boldsymbol{X_{iv}}$ = cessation (days); $\boldsymbol{\beta_5}$ = coefficient of $\boldsymbol{X_v}$; $\boldsymbol{X_v}$ = number of dry days; and $\mathcal{E}$ = random error or error factor.

The total annual rainfall, mean annual temperature, onset, cessation and number of dry days for all the districts were calculated by pooling data for the five districts. The arithmetic mean method is commonly used by researchers [40,41] because it provides accurate results due to the uniformly distributed pattern of the meteorological stations. Also, there were not much variations in the temperature values under consideration. This method was represented as:

$$P_x = (P_1 + P_2 + P_3 \ldots\ldots\ldots\ldots Pn) \Big/ n = \frac{1}{n}\sum_{i}^{n} P_i \quad (3)$$

where.

P_x = average climate data over the districts for a given time period
$P_1 P_2, P_3 \ldots\ldots\ldots P_n$ are the climate data in a given time period at districts 1, 2, 3 … … … n, respectively, within northern Ghana

Similarly, the overall average yield of each food crop was obtained by pooling the average yield for all the districts. This method has been used previously to estimate crop yields and post-harvest losses for two different districts in Ghana [42]. The D'Agostino-Pearson Omnibus normality test was performed to evaluate the normality of the data [43].

3. Results

3.1. Climate trends

3.1.1. Rainfall

Results showed variable rainfall patterns in the study districts from 1988 to 2016 (Fig. 2). The negative values of Sen's slope for four of the districts (i.e. Bole, Nanton, Kassena Nankana East and Wa) suggested a decrease in annual rainfall over the study period (1988–2016), although these trends were not statistically significant ($p > 0.05$). However, Tolon district showed a somewhat increasing pattern of annual rainfall, evidenced by the positive value of Sen's slope. During the period under consideration, Tolon district experienced the highest variation in rainfall (17.5%) which was closely followed by Nanton district (17.3%) with Wa district recording the lowest rainfall variability (14.1%).

3.1.2. Rainfall onset, cessation, length of rainy season and number of dry days

Variability in the onset, cessation and length of rainy days was statistically significant from year to year, and across the districts ($p < 0.05$) (Fig. 3). However, the variability was higher among the districts compared to the years ($p < 0.0001$). Bole district had the highest

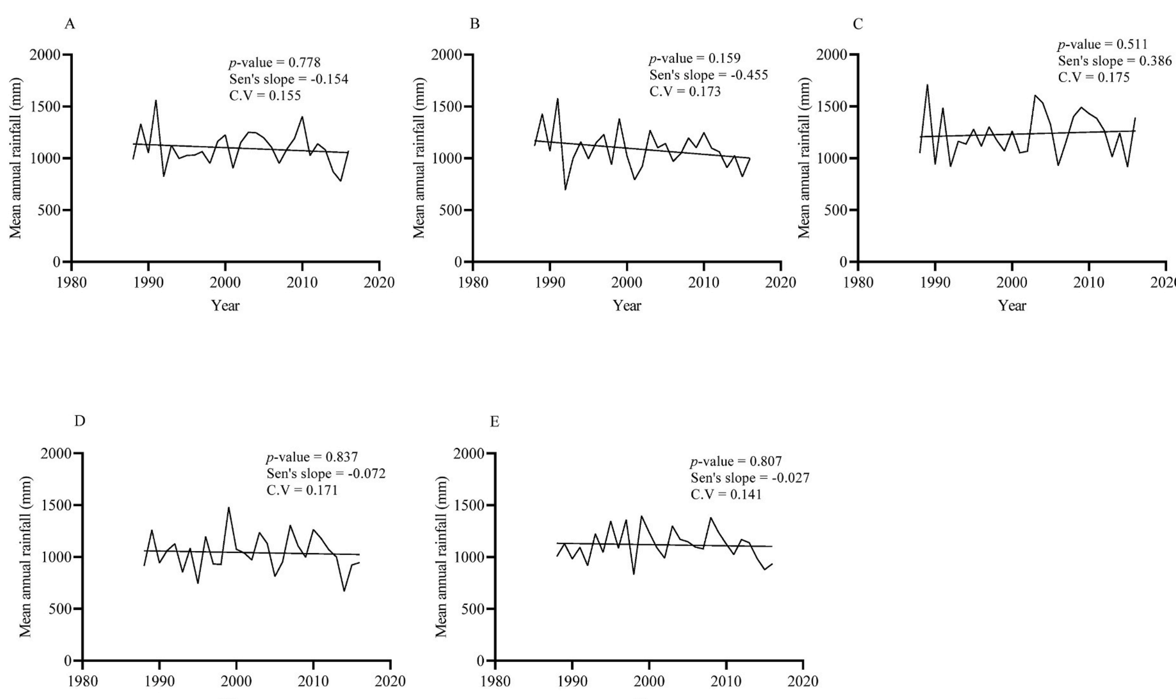

Fig. 2. Annual rainfall patterns across the districts (1988–2016); A, B, C, D, E = Bole, Nanton, Tolon, Kassena Nankana East and Wa districts respectively.

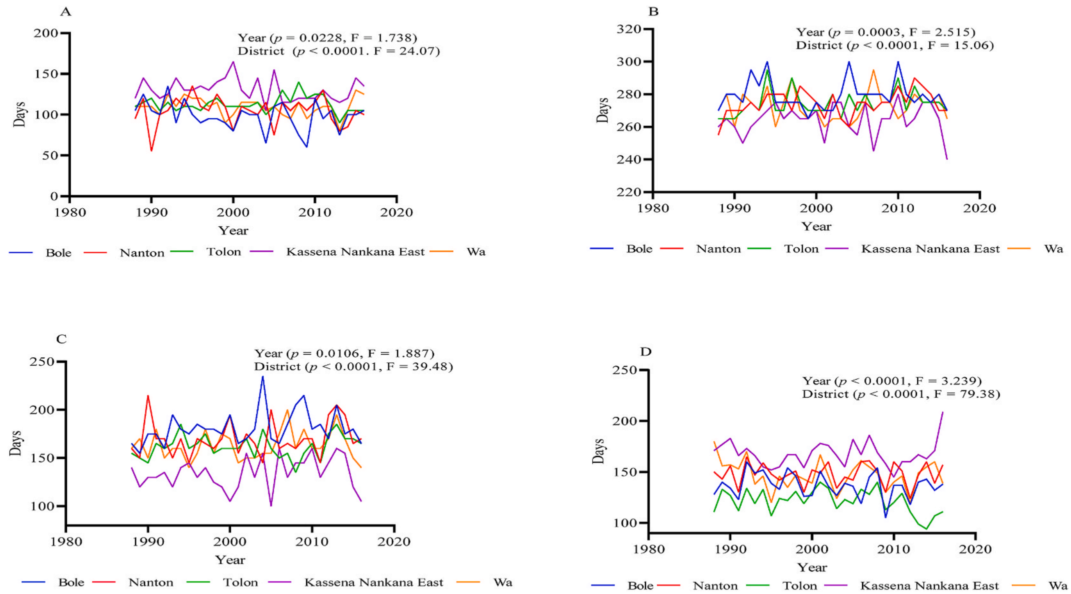

Fig. 3. Variability in onset, cessation, length of rainy days and number of dry days across the districts (1988–2016); A, B, C, D, E = Onset, cessation, length of rainy days and number of dry days respectively.

variability of rainfall onset whilst the lowest variation in the onset occurred in Tolon district (Appendix A). Moreover, the highest variation in the cessation trend was experienced in Nanton district whereas the lowest occurred in Bole district. Also, the highest variation in the length of the rainy season occurred in Bole district. Across the districts, the earliest rainfall onset was recorded on the 55th day (24th February) in 1990 in Nanton district whilst the most delayed rainfall onset occurred on the 165th day (13th June) in 2000 in Kassena Nankana East district. The earliest rainfall cessation occurred in Kassena Nankana East district on day 240 (27th August) in 2016 whilst the most delayed rainfall cessation occurred on the 300th day (27th October, 26th October and 27th October) in three different years (1994, 2004 and 2010) in Bole district. Bole district had the longest rainy season (235 days) in 2004 whilst Kassena Nankana East district had the shortest rainy season (100 days) in 2005.

Furthermore, the variability in the number of dry days was higher among the districts ($p < 0.0001$, F = 79.38) compared to the years ($p < 0.0001$, F = 3.239). Tolon district experienced the highest variability in the number of dry days per season with Nanton district recording the lowest variation in the number of dry days per season. The highest

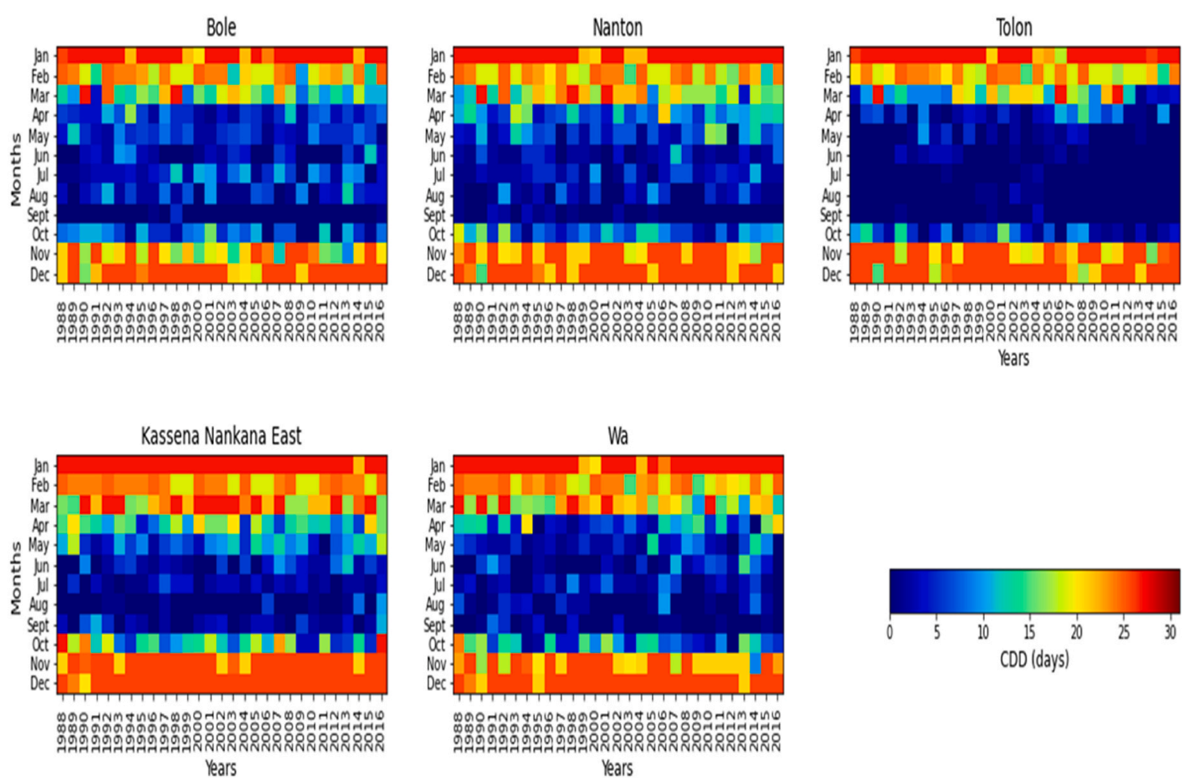

Fig. 4. Number of dry days per month for the study districts (1988–2016).

number of dry days per season (209 days) was recorded in Kassena Nankana East district in the year 2016 whilst the lowest number of dry days per season (94 days) was recorded in Tolon district in the year 2014. The occurrence of at least 15 consecutive dry days was highest in the months of January, February, March, November and December in all the study districts from 1988 to 2016 (Fig. 4). Rainfall levels were relatively high in April and became significant in May but peaked in August and reduced in volume in September in all the study districts.

3.1.3. Temperature

Mann-Kendall trend test indicated significant increase in temperature over time ($p < 0.05$) during the study period in the five study districts (Fig. 5). This is confirmed by the positive magnitudes of Sen's slopes. Among the districts, Wa and Tolon experienced the highest temperature variability (1.9%) followed by Nanton district (1.5%) whereas Kassena Nankana East district had the lowest temperature variability (1.0%).

3.2. Yield trends of selected staple food crops in the study districts

Crop yields for the selected districts had been variable for the study period (Fig. 6). Bole district experienced a steady rise in the yield of millet from 0.7 MT/ha in the year 1997 to 1.3 MT/ha in 2010 representing about 86% increase. Rice had the highest yield (2.7 MT/ha) in the district for that study period, followed by maize (2.0 MT/ha). The coefficient of variation for sorghum (38%) indicates that it had the highest yield variation. Rice yield was the highest for the period of study in the Nanton district, although it declined sharply from 3.49 MT/ha in 1995 to 0.86 MT/ha in 1997. It was closely followed by groundnut (3.39 MT/ha), which increased from 0.8 MT/ha in 2001 to 3.39 MT/ha in 2002. The coefficient of variation of groundnut (55%) indicates that groundnut had the highest variation in yield data in the study district. In Tolon district, there was a sharp increase in the yield of rice from 2.2 MT/ha in 1996 to 4.64 MT/ha in 2002, which was the highest in the district for the study period. This was followed by millet (2.25 MT/ha). The coefficient of variation of millet (50%) shows that this crop had the highest variation in yield data in the district.

In Kassena Nankana East district, rice recorded the highest yield (4.29 MT/ha) in 2008 following a sharp increase from 1.47 MT/ha in 2007. This was followed by groundnut (1.9 MT/ha) in 2016. In the same district, groundnut had the highest yield variation (36%). For Wa district, rice had the greatest yield (2.5 MT/ha) in the year 2000 after a sharp increase from 0.8 MT/ha in 1998. This was then followed by maize (1.8 MT/ha) in the same year (i.e. 2000). The coefficient of variation of rice (36%) showed the highest variation in yield data in the study district.

3.3. Effect of climate variables on the yields of selected staple food crops

The results of the multiple regression analysis revealed several significant relationships between climate variables and yield of the selected food crops (Table 2). Millet was moderately correlated with the climatic variables (multiple R = 0.544), which explained about 30% of its variation ($R^2 = 0.295$; $p > 0.05$). The positive regression coefficients indicated that annual temperature, annual rainfall, onset and cessation had positive effects on millet yield. For sorghum, the climatic variables accounted for about 32% of the variation in the yield (R^2=0.321) with cessation being the most important ($p < 0.05$). All the climatic variables, except the number of dry days and annual temperature had positive effects on sorghum yield. Only 14% of the variations in the yield of rice was explained by the climatic factors ($R^2 = 0.137$; $p > 0.05$). The variability of groundnut yield was about 43% ($R^2 = 0.425$) with annual rainfall, temperature and cessation having positive effects on the yield. However, only temperature significantly influenced the yield variation ($p < 0.05$). About 25% of the variability of maize yield was explained by the climatic variables ($R^2 = 0.254$) with annual rainfall and temperature significantly influencing its variation ($p < 0.05$). Regression coefficients indicated that annual rainfall and temperature positively affected maize yields.

4. Discussion

4.1. Climate trends

Assessment of the trend of annual rainfall and temperature in the study districts showed a variable rainfall pattern and increasing

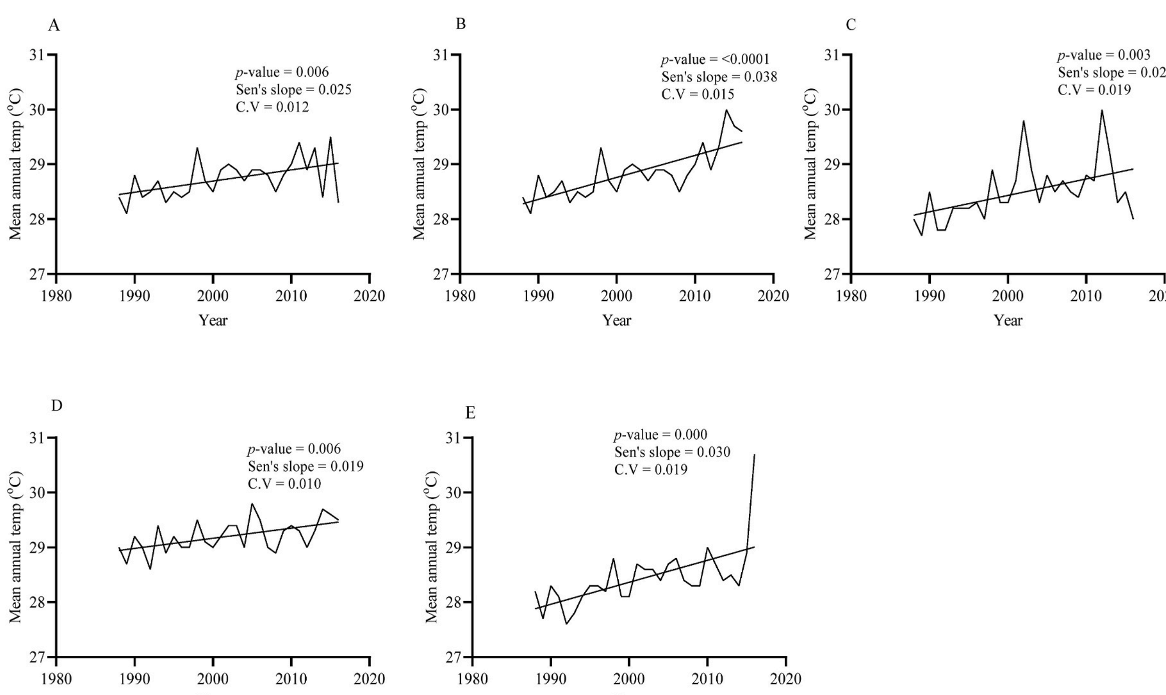

Fig. 5. Mean annual temperature across the districts (1988–2016); A, B, C, D, E = Bole, Nanton, Tolon, Kassena Nankana East and Wa districts respectively.

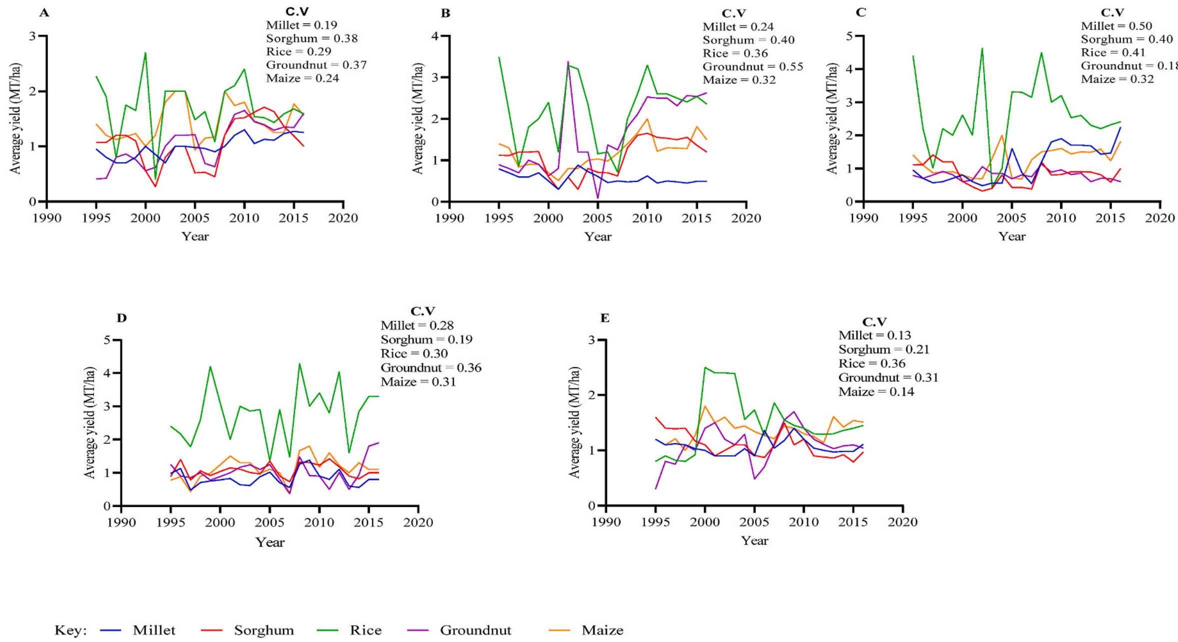

Fig. 6. Yield trends across the districts (1988–2016); A, B, C, D, E = Bole, Nanton, Tolon, Kassena Nankana East and Wa districts respectively.

Table 2
Summary output for the regression model of selected food crops.

Food crop	Variable	Coefficient	*p*-value
Millet	Mean annual temperature (°C)	1.222	0.133
	Mean annual rainfall (mm)	0.001	0.521
	Onset (days)	0.002	0.939
	Cessation (days)	0.003	0.945
	Number of dry days (days)	−0.042	0.109
	Multiple R	**0.544**	
	R square	**0.295**	
	Normality of residuals		0.812
Sorghum	Mean annual temperature (°C)	−0.159	0.880
	Mean annual rainfall (mm)	0.000	0.864
	Onset (days)	0.021	0.526
	Cessation (days)	0.082	**0.004**
	Number of dry days (days)	−0.050	0.159
	Multiple R	**0.566**	
	R square	**0.321**	
	Normality of residuals		0.698
Rice	Mean annual temperature (°C)	1.756	0.464
	Mean annual rainfall (mm)	0.004	0.497
	Onset (days)	0.059	0.432
	Cessation (days)	0.044	0.713
	Number of dry days (days)	−0.051	0.509
	Multiple R	**0.370**	
	R square	**0.137**	
	Normality of residuals		0.245
Groundnut	Mean annual temperature (°C)	4.079	**0.005**
	Mean annual rainfall (mm)	0.003	0.275
	Onset (days)	−0.021	0.591
	Cessation (days)	0.039	0.548
	Number of dry days (days)	−0.003	0.939
	Multiple R	**0.652**	
	R square	**0.425**	
	Normality of residuals		0.490
Maize	Mean annual temperature (°C)	1.863	**0.010**
	Mean annual rainfall (mm)	0.003	**0.035**
	Onset (days)	−0.022	0.517
	Cessation (days)	−0.003	0.949
	Number of dry days (days)	−0.027	0.435
	Multiple R	**0.504**	
	R square	**0.254**	
	Normality of residuals		0.751

NB: > 0.7 = strong correlation $0.3 \leq x \leq 0.7$ = moderate correlation <0.3 = weak or no correlation.

temperature in the study districts. This agrees with previous studies (Antwi-Agyei et al. [44] and Issahaku et al. [45]) suggesting that rainfall has been variable whereas temperature has been increasing in northern Ghana. The negative Sen's slopes on the trends indicated that although rainfall has been very variable, amounts perhaps have decreased slightly in the districts with the exception of Tolon district which had a slight increase in rainfall amounts. The slight increase in the amounts of rainfall in Tolon district could be attributed to the torrential rainfall which occurs in August and September annually and often leads to flooding in the district [46]. It is also important to note that Tolon district experienced the highest variation in annual rainfall in all the study districts. This could be attributed to non-linear interactions with factors such as elevation, slope and aspect, urbanization, strong winds, etc. Accurate estimation of the factors that influence rainfall variation at a place is one of the major challenges in hydrometeorology [47]. Rainfall amount and timing can influence the yield of crops. Low rainfall amounts can be detrimental to crop yield, especially if the dry periods occur during critical developmental stages [48]. Erratic rainfall pattern can also activate severe climatic events including droughts and floods, which can have unfavourable impacts on the yields of food crops [49].

Results also showed that the rainfall onset, cessation and length of rainy season varied in the years and districts from 1988 to 2016. However, the highest variation in the onset of rains and cessation were experienced in Bole and Nanton districts, respectively (Appendix A). This variation could be explained by latitudinal differences among the districts as well as the complex series of atmospheric and oceanic interactions that have increased as a result of climate change [50–52]. The high variation in the rainfall onset and the low variation in the cessation trend all occurred in Bole district possibly accounting for the high variation in the length of its rainy season over the study period (Appendix A). This finding is supported by previous studies (see Vrieling et al. [53]; Kisaka et al. [54]) suggesting that variation in the onset of rains and cessation trends could significantly affect the length of the rainy seasons. Furthermore, results also indicated variation in the number of dry days per season in the districts over the study period. The occurrence of dry days decreased from April to September but increased from October to March (Fig. 4). Increase in the number of dry days accompanied with high evapotranspiration could result in about 40% decrease in the yields of crops [27].

Regarding temperature, Wa and Tolon districts experienced the highest temperature variability. This could possibly be due to natural processes including solar variability, wind, vegetation cover and waterbodies [55]. Temperature increase reduces the yields of crops and quality of food crops through faster development of a crop thereby resulting in a shorter crop growth duration [56], and increasing the photosynthetic and respiratory cycles of crops [57]. Increase in temperature can also lead to an exponential increase in the saturation vapour pressure of air and directly damage their plant cells [58]. Rise in temperatures has also been reported to affect crops development due to environmental stress which is the principal reason for more than 50% global losses in yields of majority of crops [59] exacerbating the vulnerability of food supply [14]. Furthermore, alterations in rainfall and temperature rise could eventually result in dry spells and reduce the maturity period of crops [4].

4.2. Yield trends of selected staple food crops

The trends in crop yield varied considerably among the selected staple food crops, in agreement with a study conducted by Amikuzuno and Donkoh [10] in northern Ghana which indicated sharp and non-stationary variability among selected food crops. This finding could be linked to the fact that sorghum, millet, groundnut and maize are solely rain-fed and directly interconnected to the trend of rainfall in the study districts. This implies that annual production of these rain-fed crops followed same pattern as rainfall variability during the period under investigation (1995–2016). On the contrary, rice is partially rainfed and partially irrigated. Hence, rice recording the highest yield in all the districts is predictable because irrigation is accessible for some rice farms in that area to preserve yield losses during dry spells. For instance, delays in the onset of rains and increase in the number of dry days could accelerate the need for farmers to initiate adaptation practices such as irrigation. This is in agreement with a study conducted by Amikuzuno and Donkoh [10] which concluded that, rice farmers in Guinea Savannah agro-ecological zone practiced irrigation to safeguard yield losses during dry spells in the planting season. Kurukulasuriya and Mendelsohn [60] also reported that, irrigated agriculture is the most vital adaptation practice to reduce the impacts of climate change and variability, although less than 5% of the farmers in Ghana practise it.

Additionally, high yielding varieties of rice including “Jasmine 85”, “AGRA rice”, “Togo marshal”, “Digang”, “Nerica 1”, “Nerica 2”, and “Nabogo rice” [61] have been constantly distributed by several rice improvement research programmes in northern Ghana over the past years [10]. However, maize and millet had the second highest yield in Bole and Tolon districts, respectively. These findings are in line with a report by Council for Scientific and Industrial Research [61] that identified these crops to be vital cereals in the bid to adapt to the changing climate and address food insecurity and poverty in northern Ghana. The high yields of millet and maize recorded in those districts could be due to the introduction of high yielding and weather resistant crop varieties such as “Bihilifa”, “Ewul-Boyu”, “Obatanpa”, “Okomasa”, “Wang-Dataa” and “Sanzal-Sima” (maize varieties) and “Afribeh-naara”, “Waapp--naara”, “Kaanati”, “Akad-kom” and “Naad-kohblug” (millet varieties) [61] by farmers (Wiredu et al. [62]; Armah et al. [63]). Other hybrid maize varieties including “Mamaba”, “WACCI-M-1205”, “WACCI-M-1210” and “WACCI-M-1218”, “Kunjor-Wari”, and “Kpari-Faako” have also been supplied to farmers in Ghana. These hybrid varieties substantially enhance yields, have superior genetic potential over improved open-pollinated varieties and local varieties, and allow farmers to predict how much to plant. The cultivation of different varieties of maize and millet highlights the importance of increased agricultural biodiversity to sustainable food production in Ghana. The genetic diversity in crop varieties provides them with the ability to adapt to changing environments and to evolve by increasing their adaptation to high temperature and drought as well as their resistance to diseases, insects and parasites [64]. Furthermore, agricultural biodiversity also performs ecosystem services such as soil and water conservation, maintenance of soil fertility, conservation of biota and pollination of plants, all of which are essential for food production and human survival [64]. Lower yields of the selected staple food crops could be attributed to delays in the onset of rains, increased number of dry spells, early rainfall cessation and shorter rainy seasons recorded in the districts. Such finding agrees with previous studies [18,22,23] suggesting that delays in the onset of rains accompanied by early rainfall cessation and increased dry spells typically reduce yield of cereals.

4.3. Effect of the climatic variables on the yields of the selected staple food crops

The regression analysis showed minimal impacts of mean annual rainfall, onset, cessation, number of dry days and temperature on the yields of millet and rice. This could be due to the fact that, other factors not included in the model such as soil fertility, solar radiation, relative humidity, type of soil and better farming practices may be accountable for the variation in crop yield. These findings are in conformity with a previous study conducted in Ghana by Aninagyei and Appiah [65] suggesting that climatic variables exerted no significant effects on the quantities of grain crops produced in Akim Achiase in the Eastern Region of Ghana. Rather, non-climatic factors such as irrigation and fertilizer application are critical in grain crop cultivation in Ghana. Similarly, Amikuzuno and Donkoh [10] confirmed that yields of staple food crops were not solely dependent on climate forcing, but also on non-climatic factors. Tunde et al. [66] also made similar observation in Nigeria where they concluded that, factors such as soil fertility, availability of adequate water for crops and farm management practices contributed to the variation in yields of some selected food crops.

The results imply that non-climatic factors such as farming practices, soil fertility etc. could influence the variability in crop yields in the study region. Improvement in agronomic and farm management practices including application of fertilizers, conservation agriculture techniques including improved crop residue management, planting of improved varieties, access to irrigation facilities and farm inputs have all been recognized to influence the yields of crops [38,67–69]. Improved soil fertility as a result of traditional soil conservation practices including mulching and the use of organic manure could be important non-climatic factor in reducing the impacts of climate stresses [70]. Ayumah et al. [71] reported that improved soil fertility was the most significant non-climatic factor that can substantially affect crop yields particularly cereals such as maize, millet and sorghum. Soil variables including pH, organic matter, nitrogen and phosphorus availability have been found to correlate directly with the variation of crop yields at Bawku Municipality in northern Ghana [71]. Other studies have reported improvement in disease and pest management to positively influence crop yields [72,73].

Annual rainfall and temperature had substantial positive effects on the variability of the yields of maize (Table 2). This is because maize will need much water to thrive in hotter climates. With northern Ghana generally known to be a hotter climatic region, variability in rainfall patterns and increasing temperature trends will significantly impact the yields of these food crops. For instance, an ideal amount of rainfall can significantly raise maize yields. Drought tolerant varieties of maize can also thrive under higher temperatures and hence low levels of rainfall may not necessarily reduce the yields of maize. Maize recorded the second highest yield in Bole district in the years 2003, 2004 and 2008 as well as Wa district in the year 2000 and this is because those years also recorded a very appreciable amount of rainfall in that districts (Fig. 2). In any of the districts where maize yields were high or low for a particular year, this correlated well with the annual rainfall and temperature trend indicating how crucial the two variables are to their yield variation. Regression results also indicated that temperature had a significant positive influence on the yields of groundnut. This is because temperature is key to the survival and growth of groundnut. Previous studies (e.g., Traore et al. [27]; Prasad et al. [74]; Kakani et al. [75])

have reported that an increase in temperature causes increased evapotranspiration leading to a decline in production of groundnuts as they fight to conserve water and this can cause significant yield losses especially during their reproductive period. However, the positive relationship between temperature and groundnut yield suggests that the latter increases with the former in the study districts. This could be due to the use of drought-tolerant varieties of groundnut including Bambara groundnut (*Vigna subterranean)* in the study districts by farmers [76]. The climatic parameter which was key to the variability of sorghum yields in the study districts was rainfall cessation. Early rainfall cessation normally results in shortened rainy season especially if it is accompanied by late onset of rains. This eventually leads to water stress in the crops resulting in vital losses of yields [77,78]. It is important to note that the effect of the climatic variables on the yield was crop dependent, evidenced by the significant relationships observed for some crops while for others these were not significant.

5. Conclusions

This study assessed the effect of climate variability on the yields of some selected staple food crops in selected districts (Bole, Nanton, Tolon, Kassena Nankana East and Wa) in northern Ghana. Trend analysis of climate data suggested erratic rainfall, onset, cessation, number of dry days and increasing temperature in the study districts over the study period (1988–2016). The results also revealed variability in the yields of the five selected staple food crops (millet, sorghum, rice, groundnut and maize). Sorghum, millet and rice had the highest yield variation in Bole, Tolon and Wa districts respectively. Groundnut had the highest yield variation in both Kassena Nankana East and Nanton districts. The results showed that, annual rainfall, onset, cessation, number of dry days and temperature had statistically insignificant effects on the variability of the yields of millet and rice. The implication is that, other factors that could not be accounted for in the study such as better farming practices, better diseases and pest management control, soil type, fertility of the soil, yield improving external inputs, relative humidity, improved seed variety and technology could equally be responsible for the variation in the yields of the selected staple food crops. Thus, it is impossible to rule out the effects of non-climatic factors on the variability of the yields of staple food crops in northern Ghana. Rainfall and temperature had significant positive effects on the variability of the yields of maize.

Temperature had a significant positive influence on the yields of groundnut whilst cessation of rains was key to the variability in sorghum yields. Delays in the onset of rains normally lead to change in planting dates and enhances the risk of low crop yields. Increase in the number of dry days during rainy season can also have substantial effects on the yields of crops. The study recommends the need for adaptation practices including the use of agricultural diversification and greater use of drought tolerant varieties of these staple crops and continued investment in crop breeding programmes to enhance drought tolerance.

6. Limitations of the study and future research directions

Due to data limitations, non-climatic variables were not included in this study. Considering this, future research is recommended to take into account the inclusion of non-climatic variables to guide policy development and appropriate interventions that can ensure sustainable agricultural production in northern Ghana in the face of changing rainfall patterns. Although rainfall and temperature data were obtained for the period 1988–2016, yield data for the selected food crops could only be obtained from the Ministry of Food and Agriculture Departments at the study districts for the period 1995–2016 due to unavailability of data.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Pairwise comparison test results

Onset					
Districts	Bole	Nanton	Tolon	Kassena Nankana East	Wa
R^2	**0.087**	0.003	0.000	0.038	0.021
F	2.565	0.079	0.001	1.079	0.588
Pr > F	0.121	0.781	0.982	0.308	0.450
Cessation					
Districts	Bole	Nanton	Tolon	Kassena Nankana East	Wa
R^2	0.0011	**0.098**	0.055	0.0012	0.0014
F	0.029	2.943	1.580	0.033	0.038
Pr > F	0.867	0.098	0.220	0.857	0.846
Length of rainy days					
Districts	Bole	Nanton	Tolon	Kassena Nankana East	Wa
R^2	**0.073**	0.033	0.023	0.032	0.017
F	2.115	0.932	0.628	0.898	0.476
Pr > F	0.157	0.343	0.435	0.352	0.496
Number of dry days					

(*continued on next page*)

(*continued*)

Onset					
Districts	Bole	Nanton	Tolon	Kassena Nankana East	Wa
Districts	Bole	Nanton	Tolon	Kassena Nankana East	Wa
R^2	0.035	0.000	**0.121**	0.005	0.064
F	0.991	0.008	3.721	0.147	1.831
Pr > F	0.328	0.930	0.064	0.704	0.187

R^2 = Coefficient of determination.

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