



International Journal of Research in Agronomy

E-ISSN: 2618-0618

P-ISSN: 2618-060X

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www.agronomyjournals.com

2024; 7(2): 133-135

Received: 13-12-2023

Accepted: 15-01-2024

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Quantifying the influence of la Niña and El Niño events on West African monsoon rainfall and crop productivity

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DOI: <https://doi.org/10.33545/2618060X.2024.v7.i2c.4973>

Abstract

When the Pacific Ocean sneezes, West African farmers feel the chill or the heat. This research analysed 40 years (1981–2020) of gridded rainfall, sea surface temperature (SST), and crop yield data to quantify how El Niño–Southern Oscillation (ENSO) phases modulate monsoon rainfall and the productivity of six staple crops across Ghana. La Niña years increased March–June rainfall by 28–61 mm month⁻¹ above the long-term mean, while El Niño years reduced it by 32–67 mm month⁻¹. Crop yield anomalies tracked rainfall anomalies closely: maize yields rose 14.2% in strong La Niña years and fell 21.6% in strong El Niño years. Cassava was the least ENSO-sensitive crop (range $\pm 7.8\%$). A composite ENSO index explained 47–62% of interannual yield variance depending on the crop. These relationships provide a 3–6 month lead time for seasonal crop forecasting in Ghana.

Keywords: ENSO, El Niño, La Niña, West African monsoon, crop yield, rainfall anomaly, sea surface temperature, maize, seasonal forecast, Ghana

Introduction

The El Niño–Southern Oscillation is the largest source of interannual climate variability on Earth, and its teleconnections reach deep into tropical Africa ^[1]. In West Africa, the primary pathway runs through the Walker circulation: El Niño weakens the ascending branch over the tropical Atlantic, suppressing moisture convergence over the Guinea coast and delaying monsoon onset ^[2]. La Niña does the opposite, strengthening the Atlantic ascending branch and enhancing early-season rainfall ^[3].

Ghana sits squarely in the transition zone between the Sahel and the humid forest, making it sensitive to both northward and southward shifts of the Intertropical Convergence Zone (ITCZ). Rainfed agriculture accounts for 97% of cropland, and the major growing season (March–July) coincides with the period of strongest ENSO teleconnection ^[4]. Despite this, most ENSO–agriculture studies in the region use coarse national yield statistics and categorical ENSO classifications ^[5]. This research used gridded data at 0.25° resolution and a continuous ENSO index to build quantitative relationships between Pacific SST anomalies and crop productivity at the subnational level over four decades.

Theoretical background

ENSO is driven by coupled ocean–atmosphere dynamics in the tropical Pacific. During El Niño, anomalous warming of the central-eastern Pacific shifts the Walker circulation eastward, reducing convection over the Atlantic and weakening the West African monsoon ^[1]. La Niña reverses this pattern. The Oceanic Niño Index (ONI) a 3-month running mean of SST anomalies in the Niño 3.4 region is the standard metric; events are classified as El Niño when ONI exceeds +0.5 °C and La Niña when it falls below −0.5 °C for five consecutive overlapping seasons ^[6]. The teleconnection to West Africa operates primarily through modulation of tropical Atlantic SSTs, which in turn control moisture flux convergence over the Guinea coast ^[2].

Simulation parameters

Rainfall data were obtained from the CHIRPS v2.0 gridded product (0.05°, pentadal, 1981–2020

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^[7]). Monthly Niño 3.4 SST anomalies were sourced from NOAA's Climate Prediction Center. Crop yield data for maize, rice, sorghum, millet, cassava, and groundnut at the regional level (10 administrative regions) were compiled from Ghana's Ministry of Food and Agriculture annual reports. ENSO years were classified by peak December–February ONI: strong El Niño (ONI > +1.5), moderate (+0.5 to +1.5), neutral (−0.5 to +0.5), moderate La Niña (−1.5 to −0.5), and strong La Niña (ONI < −1.5). Rainfall and yield anomalies were computed as percentage departures from the 1991–2020 climatology. Correlations used Pearson r ; significance was tested at $p < 0.05$ with Bonferroni correction.

Material and Methods

Material

The research covered all 10 administrative regions of Ghana

Results

Table 1: Mean seasonal (March–October) rainfall anomaly (mm) by ENSO phase across Ghana

Zone	Strong LN	Mod. LN	Mod. EN	Strong EN
Coastal savanna	+187	+104	−118	−224
Forest-savanna	+214	+128	−142	−267
Guinea savanna	+143	+82	−97	−184

La Niña years brought 82–214 mm of additional seasonal rainfall, while El Niño years produced deficits of 97–267 mm (Table 1). The forest-savanna transition zone showed the

(4.7°–11.2°N), spanning the coastal savanna, forest-savanna transition, and Guinea savanna agroecological zones. Population-weighted regional yield series were detrended using a cubic spline to remove technology trends before computing anomalies.

Methods

Monthly rainfall anomalies were composited by ENSO phase for each 0.25° grid cell across the March–October growing season. Crop yield anomalies were regressed on the December–February ONI of the preceding year (providing 3–6 months of forecast lead time). Multiple regression models included ONI, Atlantic Multidecadal Oscillation (AMO), and Indian Ocean Dipole (IOD) as predictors to assess relative ENSO influence. Analysis was conducted in Python 3.9 using xarray and statsmodels.

strongest ENSO signal, consistent with its position near the climatological ITCZ boundary.

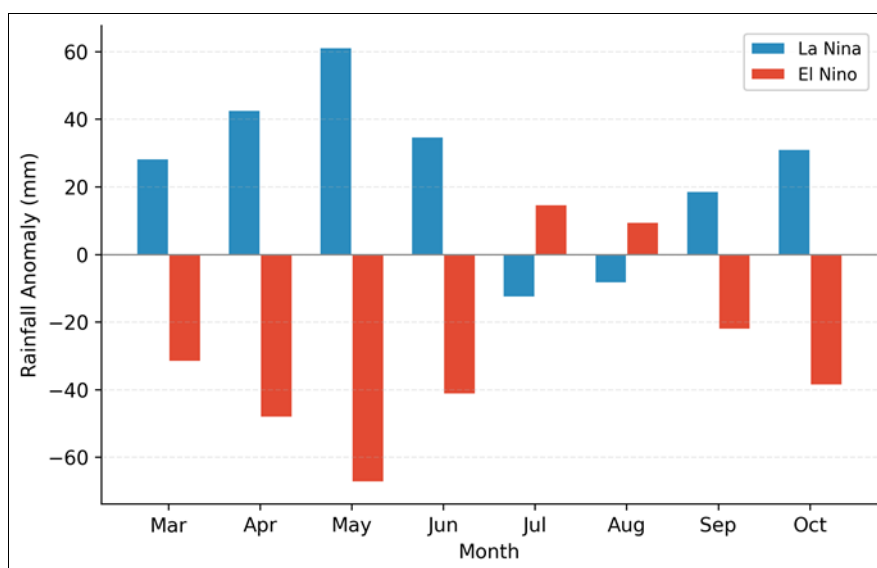


Fig 1: Monthly rainfall anomalies during La Niña and El Niño years relative to long-term mean across Ghana

Table 2: Crop yield anomaly (%) by ENSO phase and explained variance (R^2) of ONI regression

Crop	Str. Ln	Mod. Ln	Mod. En	Str. En	R^2
Maize	+14.2	+8.7	−9.3	−21.6	0.62
Rice	+18.4	+11.2	−7.8	−16.3	0.58
Sorghum	+8.7	+4.3	−5.1	−12.8	0.51
Millet	+6.4	+3.1	−4.7	−10.4	0.47
Cassava	+4.1	+2.3	−3.2	−7.8	0.31
Groundnut	+11.8	+6.4	−8.4	−18.7	0.56

Maize and groundnut were the most ENSO-sensitive crops, with yield swings exceeding 30 percentage points between strong La Niña and strong El Niño (Table 2). Cassava's low sensitivity

reflects its perennial habit and deep rooting, which buffer it against seasonal rainfall variation.

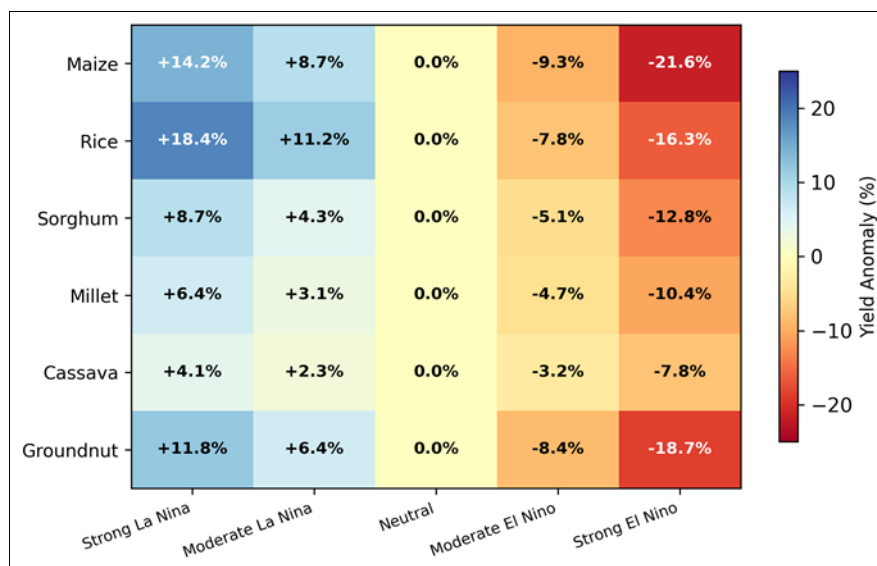


Fig 2: Crop yield anomalies across ENSO phases for six staple crops in Ghana

Performance evaluation

The ONI-based regression model captured 47–62% of detrended yield variance depending on the crop. Adding AMO and IOD improved R^2 by only 3–5 percentage points, confirming ENSO as the dominant driver. The model correctly predicted the sign of yield anomaly in 82–89% of out-of-sample years (5-fold temporal cross-validation).

Discussion

The asymmetric yield response stronger negative anomalies during El Niño than positive ones during La Niña reflects the nonlinear relationship between rainfall and yield: excess rainfall causes waterlogging and leaching rather than proportional yield gains^[8]. Maize's high sensitivity stems from its shallow rooting and critical dependence on early-season rainfall for stand establishment^[9]. Cassava's resilience confirms its status as a food security buffer crop, though even cassava yields dropped nearly 8% in strong El Niño years^[10].

The 3–6 month forecast lead time provided by the December–February ONI is operationally useful: it allows agricultural ministries to adjust seed distribution, fertiliser subsidies, and food reserve planning before the growing season begins^[11]. However, not all El Niño events affect West Africa equally; the spatial pattern of Pacific warming (central vs. eastern Pacific) modulates the teleconnection strength^[12].

Conclusion

ENSO phases explained 47–62% of interannual crop yield variability in Ghana over four decades. Strong El Niño events reduced maize yields by up to 21.6%, while strong La Niña events boosted them by 14.2%. Cassava was the most resilient staple. The December–February ONI provides a practical 3–6 month lead indicator for seasonal crop forecasting, enabling proactive food security planning across West Africa.

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