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Precipitation anomalies generated by the El Niño and La Niña Phenomena and their impact on theAgriculture of the Department of Atlántico in Colombia

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Abstract: *The Department of Atlántico, located on the northern coast of Colombia, recurrently experiences precipitation deficits or excesses - climate anomalies produced by extreme phases of the El Niño/La Niña–Southern Oscillation (ENSO) cycle. Under El Niño conditions, below-average amounts of precipitation are observed in the area, while La Niña phase generates above normal precipitation. This interannual variability of precipitation impacts the crops of sesame, plantain, maize, cassava, beans, cotton, and sorghum. Results obtained indicate that sesame and banana yields increase when rainfall is above average (usually under La Niña conditions) during the short dry season and both the first and second rainy seasons. The above-average rainfall in the dry season has a positive impact on cassava yields. Corn yields increase if the recorded rainfall in the short dry season is above average and decrease under above-average precipitation in the second rainy season. Bean yields decrease when rainfall is above average during the first and second rainy seasons and increase when rainfall is above average in the short dry season. Cotton yields decrease in cases of above-average rainfall in the second rainy season, while sorghum does not present noticeable responses to precipitation anomalies.*

Keywords: *Climatevariability in Colombia, El Niño Phenomenon, La Niña Phenomenon, Agriculture in Colombia.*

1.Introduction

Agriculture playsan important role in the food security, employment (7.5%), and socioeconomic processes (trade, agribusinesses) of the Departmentof Atlántico, located on the northern coast of Colombia; however, it occupies a secondary position in departmental economy because of its relatively low contribution to the department's gross domestic product (GDP), accounting for only 3.84% together withforestry andfishing [12]. Climate anomalies usually have an adverse socioeconomic impact on the local economy and, as a result, any variability in climate affects the department's agricultural production as cropping cycles depend on the annual cycle of rains [25]. The 2008–2011 Development Plan for the Department of Atlántico states that the poor performance of Atlántico's agriculture sector can be partly attributed to prevailing geographicand climatic conditions, which indicates not only the important role played by climate in the department's agriculture but also the degreeof dependency andvulnerability of local farmers before climatic conditions and any anomaly [12].

Climate recurrently undergoes transient or long-term changes that affect agricultural production. The El Niño and La Niña phenomena, for example, induce climatic anomalies in different regions worldwide that have a marked impact on agriculture [6, 7, 10], including Colombia (5, 16]. [8]analyzed the impact of climate anomalies on the production of small maize farmers in Mexico and found that they affected prices and local socioeconomic patterns. Analysis results highlighted the importance of understanding climate variability and climate prediction. [22]reported that, on the occasion of the 1997–1998 El Niño event in Mexico, maize production dropped approximately 3 million tons and damages were close to US$460 million. A study conducted by [20] linking climate variability, agriculture, and GDP for South Africa revealed a strong impact of the extreme phases of the El Niño/La Niña–Southern Oscillation (ENSO) cycle on agriculture and, hence, on GDP. [15], on the other hand, showed the important effect of the interannual variability of precipitation and seasonal temperatures on maize production in Missouri, USA. Similar studies highlighting the relationship between climate variability and agricultural production have been carried out in other regions of the world, for example by [27] for grain production (mainly maize) in Ceará, Brazil, and by [24] for rice in Luzon, Philippines. [13]studied the impact of seasonal temperatures on sugarcane production in Louisiana, USA, and found that fluctuations of annual

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production were determined by interannual fluctuations of the mean maximum temperature of August, the mean minimum temperature of February, soil moisture between April and September, and the occurrence of hurricanes in the fall.

In the case of Colombia, studies conducted by the Institute of Hydrology, Meteorology, and Environmental Studies (IDEAM) in 1998 [17], by IDEAM and the General Directorate for Disaster Prevention and Relief (DGPAD) in 2002 [19], and [23] evidenced climate anomaliesassociated withEl NiñoandLa Niñain the country and served as basis to inferclimate anomaliesobserved in the department of Atlántico. The study conducted by [23] revealed that theaverage air temperature in the part of the Caribbean where the department of Atlántico is located presented a highpositive correlation with sea surface temperature (SST) anomalies in the El Niño 3.4 region, while the correlation with precipitation was negative. The studies conducted by [17] and [18] indicated that there is a deficit in precipitation in the Caribbeanregionwhen El Niño occurs in the Pacificand, conversely, excessiverain whenLa Niñaoccurs. The specific analysis ofthe interannual variabilityof precipitationfor the department of Atlántico [25, 26]confirms thatthe volumeof precipitationinthe region decreases underthe El Niño phenomenonandincreases under La Niña.

Althoughseveral authors[1, 2, 6]have shownthe relationshipbetween climate/climate variability and agricultural productionin Colombia, only a few studies have incorporated this variable to explain the performanceof the agricultural sector. It was onlybecause of thedisastrouseconomic consequencesbrought about by the 1991–1992 El Niño event in Colombia that the impact ofextreme phasesof climate variabilityondifferentsocioeconomic sectors, particularly agriculture, has been analyzed [4, 5, 16, 19]. Furthermore,[9]showedthe effectsof climate anomaliesassociated withEl Niñoonpotato productionin the highlands of the departments of Cundinamarca. These effects were also analyzed, for example, in the case of coffee[2, 14]andoil palm [3].

This paper presentsthe resultsof the impact analysisof climate anomaliesassociated with the El Niño andLa Niña phenomena on agricultural production in the department of Atlántico.

2. Study area

The department of Atlántico is located in northern Colombia(Figure1) and is dominated by flat lowlands. Its main orographic systems are the mountain ranges of Serranía de Piojó located to the northeast, with its highest peak Loma La Vieja (530 m above sea level); Serranía de Luruaco and the hill Loma delCaballo located in northern part of the Serranía de Turbaco in southwestern Atlántico; and the hills Loma del Coco and Loma de Cabezade Vaca(250 m above sea level) located in the municipality of Manatí. Wetlands cover most of the department between theMagdalenaRiver and the Canal del Dique, a 113-km-long artificial canal built to facilitate navigation between Cartagena and the Magdalena River.

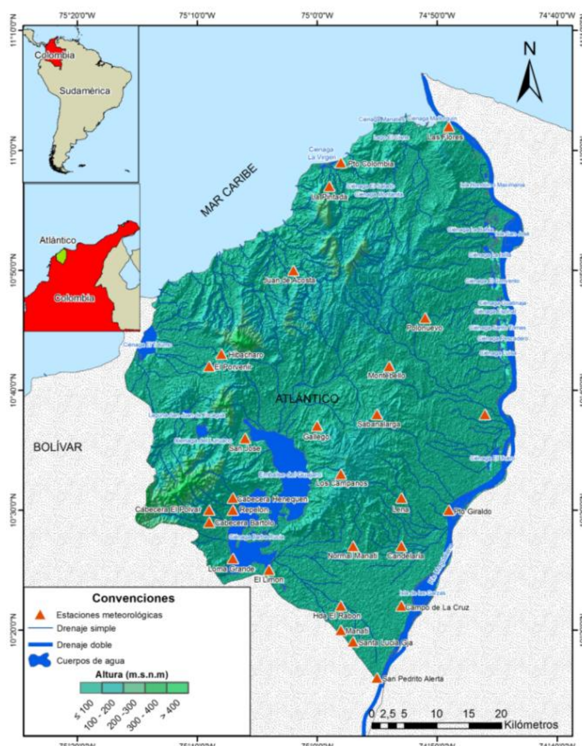

Figure 1. Locationand delimitation ofthe department of Atlántico, Colombia, with physiography, hydrography, andlocation ofweather stations which data was usedfor the analysis in this study.

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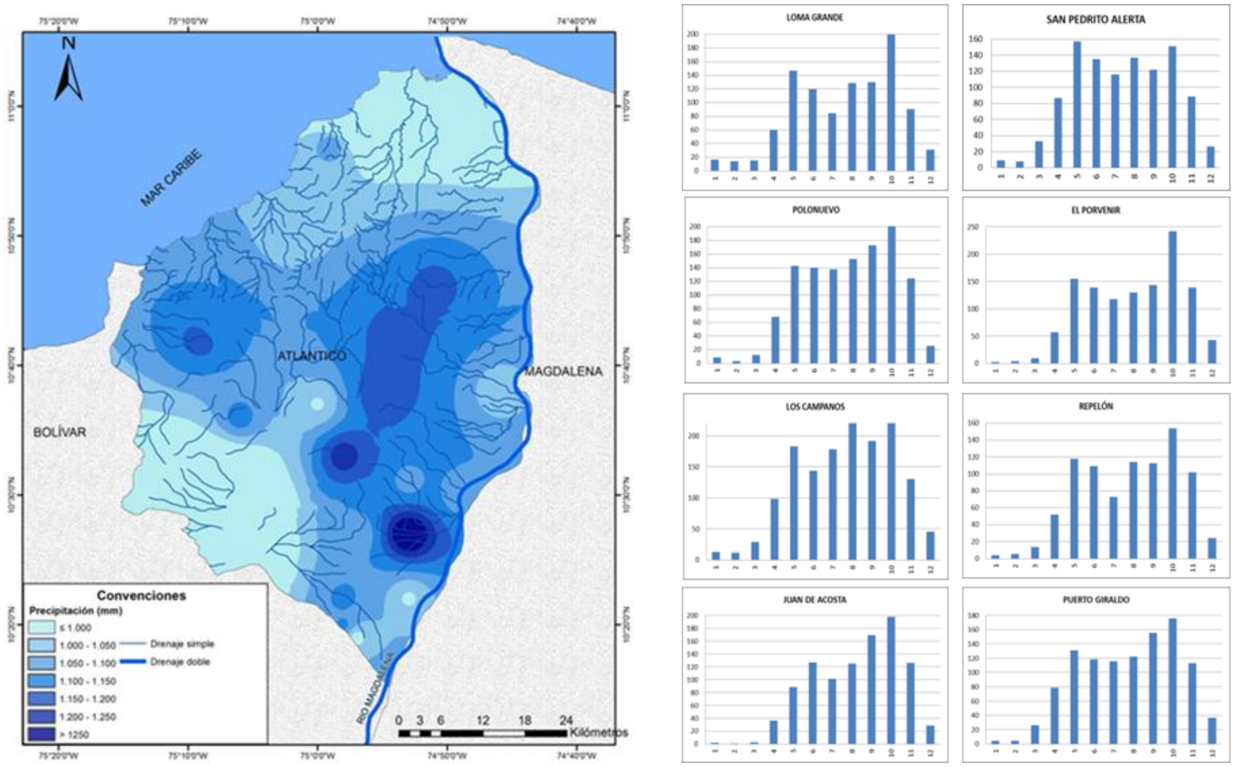

Figure 2. Spatial distribution ofannual precipitation(left) andannual precipitation cycle (right) in several localities of the department of Atlántico, Colombia.

Over 700 km^2 of the departmentof Atlántico, 41% of its total area, have soils suitablefor agriculture. Of this area, 16.6% is currently dedicated to agriculture and, of the area under cultivation, 93.1% corresponds toannual cropsand 6.9% to permanent crops, which in most cases are characterized bylow productivity, poor crop management, andpoor use of technological tools—conditions that makes them morevulnerable toextreme phasesof climate variability. Insuchcircumstances, the regionalfood supplyis not enough stable and in anomalous climate conditionsdepends heavily ofneighboring regions or of importing from another regions of the countryto satisfy its food demand [11].

3. Materials and Methods

The relationshipofthree components—conditionsin the tropical Pacific(El Niño orLa Niña), regionalclimate variability(climate anomalies), agricultural production of the department of Atlántico—is analyzed using the following variables:

- Conditions of thetropical Pacific Ocean(El Niño and La Niña). These were determined based on the OceanicNiñoIndex(ONI) corresponding to the period 1966–2010, obtained fromthe databaseof the United States agency NationalOceanic and Atmospheric Administration (NOAA - http://www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml), accessed on 30 May 2011, which corresponds tothe previous versionpublished inthefirst semester of 2012.
- Climate variabilityin the departmentof Atlántico. Thevariability of a monthly precipitation index(PI),calculated fromdata recorded at weather stationsestablished in the region and facilitated by IDEAM, was determined. The initial series contained monthlyprecipitation datafrom 37pluviometric, pluviographic, and climatological stations distributedas shownin Figure1. Data quality control was performed according to [25] and data from only 22 stations were found suitablefor analysis. PIs were calculated for these 22data sets.
- Agricultural production in the department of Atlántico. Agricultural statistics corresponding to the yieldsof the region’s main crops(sorghum, maize, plantain, cassava, beans, sesame, and cotton)

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were collected for the period1976–2003 from the data bases of specialized agenciessuch as Colombia's Ministryof Agriculture and Rural Development (MADR) andthe Secretariats of AgricultureandPlanning of the department of Atlántico, as well as from statistical yearbooks of the Governor's Office of Atlántico.

To analyze the relationshipbetweenthe variability ofprecipitation and yields, [25]defineda yield index(YI) that showed the interannual variability of yields to make it comparable with the PI.

4. Results

In the beginning of this study, it was explored the relationship between the regional seasons (annual precipitation cycle) and the crops calendar. The Figure 3 shows the phases of the crops and the crops practices compared with the annual cycle of precipitation. When the last is disrupted by any anomaly, there is an impact in the crops phase with a direct effect on the yields.

The results divide in two parts: precipitation interannual variability in the Department of Atlántico and theimpact caused by the extreme phases of this precipitation variability on crop yields.

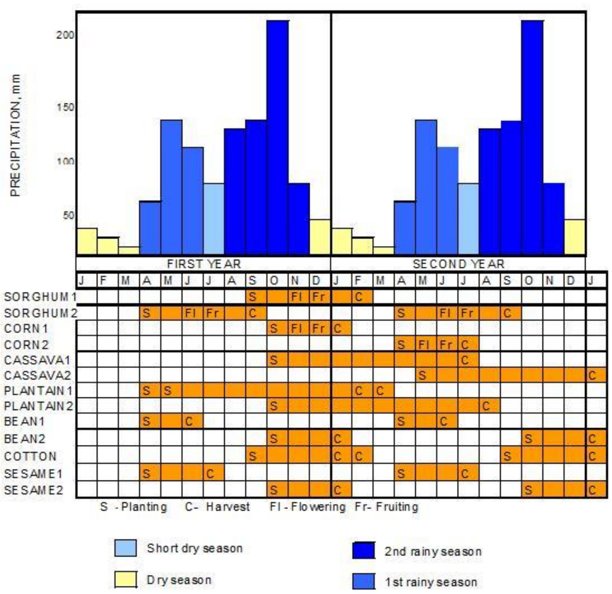

Figure 3.Annual cycle of precipitation in the region, the phenological phases (flowering and fruiting) of different cropsand time of cultural practices (planting and harvesting). (The short dry season is locally called "Veranillo de San Juan" or simply "veranillo")

4.1.Interannual variability of precipitation in the region

Figure 4 presents the sequencesof PIs calculatedfor differentweather stationsdistributed throughout the region, and the smoothings that help differentiate the interannual variability (fluctuations of the dark blue line) from the intraseasonal variability (oscillations of the light blue line). Because of space restrictions, the sequences of only six of the 22 stations analyzed are included; however, theseare representativeofthevariabilityof precipitation of the department of Atlántico, which is similar throughoutthe zone.

Regarding the interannual variability of PIs, the successionofperiodswith low rain(f negative values)andperiods ofheavy rainfall(extreme predominance ofpositive values) can be clearly observed, indicating that the region is recurrentlyaffected bythis typeofclimate anomalies (Figure 3). An inverse relationship can be established when the interannual variability of PIs is compared with ONIoscillations. Positivephases of ONI correspond to negative phasesofthe interannual variability of PIs and vice versa, which meansthat precipitation decreases in the region in the presence of El Niño(high, positive ONI values) and increases under the influence ofLa Niña(negative ONI values).

Figure5 shows thespatialdistributionofthecorrelation coefficients, evidencing a markedresponsetoEl NiñoorLa Niña in terms of precipitation inwesternand central Atlántico, above which are precipitation nuclei with relatively high correlation coefficients (between -0.3 and -0.5).

4.2. The impact of precipitation variability on regional crop yields

Table 1 presentsthe correlation coefficients(***r***) between the interannual performance of seasonal PIs and the YIs of different crops(1-year time difference, meaning that the PIs correspond to the year before that of the given YIs) for eachof the 22points analyzed.Figure6 shows the spatial distribution ofthese coefficientsfor different crops. For maize, data show a general lackof correlation between the interannual variability of seasonal PIs and the interannualfluctuations of YIs. Prevailing***r***values were between -0.2and0.2.However, for both rainy seasonsa weakinverse relationship was perceived in areas of northern and southwestern Atlántico. For the secondrainyseason, a nucleus with ***r***<-0.5 was even visible in the northern part of the

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department, evidencing a more pronounced relationship between PIs and YIs.

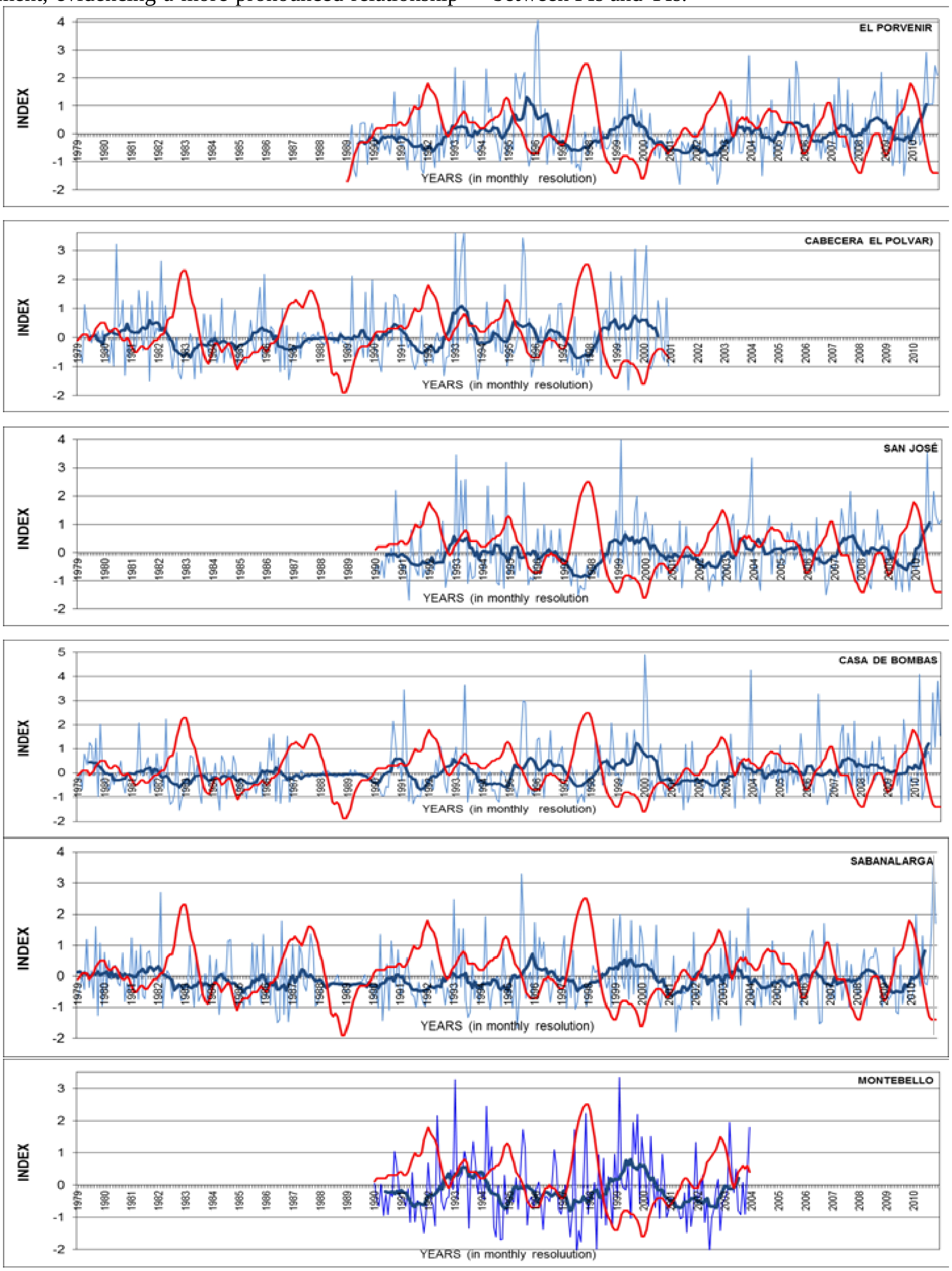

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Figure 4. Seriesofprecipitation indices(PIs) for differentweather stations of the department of Atlántico, Colombia (thin blue line) and smoothing with an 11-point moving average (thick blue line) comparedwith the ONItime series(red line). (Source: [25]).

Table 1. Correlation coefficients (***r***) for series of yield indexes (YIs) of different cropsand precipitation indexes (PIs) corresponding to four climatic seasonsfor the 22 points of measurement. (Source: [25])

1 — LOMA GRANDE

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	-0,5	-0,3	0,1	0,6	-0,1	0,0	0,1
1st RAINY SEASON	-0,3	0,1	0,2	0,4	0,1	0,0	-0,1
VERANILLO	-0,1	0,0	0,1	0,4	0,1	0,6	-0,1
2nd RAINY SEASON	-0,3	0,0	0,0	0,4	0,2	-0,1	-0,1

2 — NORMAL MANATÍ

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	-0,1	-0,1	-0,2	0,2	0,2	0,1	-0,2
1st RAINY SEASON	0,1	0,0	0,3	0,3	0,2	0,7	-0,2
VERANILLO	-0,3	0,1	0,1	0,2	-0,5	0,2	0,2
2nd RAINY SEASON	-0,2	0,1	0,3	-0,2	-0,3	0,0	-0,3

3 — PONEDERA

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	0,2	-0,1	-0,1	0,1	0,4	0,1	-0,2
1st RAINY SEASON	0,1	0,0	0,1	0,2	0,4	0,5	-0,5
VERANILLO	0,2	0,1	-0,2	-0,2	-0,1	0,0	0,4
2nd RAINY SEASON	-0,2	0,0	0,5	0,1	0,0	0,1	0,3

4 — SABANALARGA

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	0,0	-0,3	0,1	0,4	0,3	0,3	-0,2
1st RAINY SEASON	-0,3	-0,1	0,1	0,4	-0,2	0,0	-0,5
VERANILLO	0,3	0,2	0,1	0,1	0,0	0,5	0,2
2nd RAINY SEASON	0,3	0,3	0,0	0,1	0,2	0,5	-0,1

5 — LOS CAMPANOS

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	-0,2	-0,2	0,2	0,4	-0,1	0,5	-0,3
1st RAINY SEASON	0,0	-0,4	0,6	0,5	0,1	0,3	-0,4
VERANILLO	-0,1	-0,1	0,2	0,2	-0,4	0,4	0,0
2nd RAINY SEASON	0,0	-0,2	0,4	0,4	-0,3	0,4	-0,4

6 — PUERTO GIRALTO

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	0,2	0,0	-0,4	-0,1	0,3	-0,2	0,0
1st RAINY SEASON	-0,1	-0,3	0,4	0,1	0,7	0,4	-0,2
VERANILLO	0,2	-0,1	0,0	0,1	0,2	-0,1	0,5
2nd RAINY SEASON	-0,3	0,2	0,2	0,1	-0,2	0,3	-0,4

7 — LENA

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	0,1	0,1	-0,4	-0,1	0,4	0,2	-0,1
1st RAINY SEASON	0,0	0,1	-0,1	-0,1	0,3	0,2	-0,1
VERANILLO	0,2	0,3	0,0	-0,3	-0,3	-0,2	0,3
2nd RAINY SEASON	-0,1	0,3	-0,2	0,3	0,1	0,3	-0,4

8 — POLONUEVO

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	0,2	-0,3	0,0	0,0	-0,1	0,2	-0,2
1st RAINY SEASON	-0,2	-0,1	0,1	0,1	0,2	0,3	0,0
VERANILLO	-0,2	0,0	0,2	0,2	0,2	0,4	0,3
2nd RAINY SEASON	0,1	0,2	0,1	0,0	0,2	0,6	0,0

9 — SAN PEDRITO ALERTA

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	0,0	0,0	-0,1	0,3	0,1	0,1	-0,2
1st RAINY SEASON	-0,1	-0,1	0,3	0,1	-0,1	0,2	-0,3
VERANILLO	0,4	0,2	-0,2	0,1	0,4	0,5	0,3
2nd RAINY SEASON	-0,1	-0,2	0,4	0,0	0,0	0,6	-0,3

10 — HACIENDA EL RABÓN

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	-0,1	0,0	-0,4	0,0	0,1	0,0	-0,1
1st RAINY SEASON	0,1	0,3	0,2	0,0	0,1	0,4	-0,5
VERANILLO	0,0	0,2	0,0	0,2	-0,2	0,6	-0,2
2nd RAINY SEASON	0,1	0,3	0,3	-0,2	0,4	0,2	0,2

11 — CANDELARIA

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	-0,3	-0,3	0,1	0,3	-0,6	-0,3	0,2
1st RAINY SEASON	-0,2	-0,1	0,1	0,3	0,6	0,6	-0,4
VERANILLO	-0,4	-0,1	0,0	0,3	-0,7	-0,1	0,0
2nd RAINY SEASON	-0,4	0,0	0,4	-0,1	-0,8	0,1	-0,1

12 — EL PORVENIR

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	0,0	-0,2	-0,3	0,5		0,0	0,0
1st RAINY SEASON	0,3	-0,1	0,6	0,0		0,7	-0,1
VERANILLO	0,5	0,3	0,4	-0,3		0,6	0,3
2nd RAINY SEASON	-0,1	0,2	0,4	-0,3		0,4	-0,3

13 — CABECERA BARTOLO

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	0,2	0,4	0,0	0,1	-0,2	-0,2	-0,1
1st RAINY SEASON	-0,3	-0,1	0,4	0,2	-0,1	0,2	-0,2
VERANILLO	-0,1	-0,1	0,6	0,5	0,0	0,5	-0,3
2nd RAINY SEASON	-0,5	0,1	0,3	0,3	-0,2	-0,2	-0,2

14 — CABECERA EL POLVAR

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	-0,2	0,3	-0,1	-0,3	-0,2	-0,5	-0,2
1st RAINY SEASON	-0,2	0,1	0,2	0,1	0,0	0,1	0,0
VERANILLO	0,0	0,1	0,6	0,2	-0,2	0,7	-0,1
2nd RAINY SEASON	-0,2	0,3	0,2	0,1	-0,3	0,0	-0,1

15 — SAN JOSÉ

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	0,0	0,4	-0,3	0,3		0,2	-0,1
1st RAINY SEASON	0,2	0,3	0,4	-0,7		0,3	0,0
VERANILLO	0,5	0,3	0,1	-0,6		0,5	0,5
2nd RAINY SEASON	-0,1	0,2	0,0	0,5		0,1	-0,1

16 — CABECERA HENEQUEN

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	-0,3	-0,3	0,2	0,6	-0,1	-0,1	-0,3
1st RAINY SEASON	0,0	0,0	0,7	0,3	0,2	0,5	-0,3
VERANILLO	-0,2	0,1	0,1	0,5	-0,2	0,5	-0,2
2nd RAINY SEASON	-0,3	0,0	0,4	0,1	-0,6	-0,2	-0,1

17 — REPELÓN

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	-0,2	0,0	-0,1	0,2	0,3	0,0	0,0
1st RAINY SEASON	-0,2	0,0	0,3	0,1	0,4	0,2	0,0
VERANILLO	0,0	0,0	0,1	0,2	-0,2	0,3	0,0
2nd RAINY SEASON	-0,4	0,2	0,2	0,2	-0,4	0,3	-0,1

18 — CASA DE BOMBAS

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	-0,3	0,0	-0,2	0,2	-0,2	0,1	-0,3
1st RAINY SEASON	0,1	0,0	0,5	0,1	0,5	0,4	-0,3
VERANILLO	-0,1	0,0	0,3	0,4	-0,3	0,4	-0,1
2nd RAINY SEASON	-0,2	0,3	0,3	-0,1	-0,5	0,2	-0,2

19 — HIBÁCHARO

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	0,1	0,1	-0,2	0,0	0,0	-0,3	0,2
1st RAINY SEASON	0,0	-0,3	0,2	0,0	0,4	0,2	0,1
VERANILLO	0,1	-0,3	0,3	0,2	0,2	0,3	0,0
2nd RAINY SEASON	0,0	0,0	-0,1	0,3	0,0	-0,3	0,1

20 — LAS FLORES

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	-0,2	-0,1	0,1	0,4	0,2	0,4	-0,5
1st RAINY SEASON	-0,1	-0,2	-0,1	0,6	0,5	0,0	-0,3
VERANILLO	-0,3	-0,3	-0,1	0,3	-0,2	-0,2	-0,3
2nd RAINY SEASON	-0,3	0,0	-0,1	0,3	-0,1	0,1	-0,4

21 — PUERTO COLOMBIA

ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	0,0	0,0	-0,3	0,2	-0,2	-0,3	0,0
1st RAINY SEASON	-0,4	-0,2	0,3	0,3	0,1	0,0	-0,2
VERANILLO	0,4	0,0	-0,2	-0,2	0,4	0,0	0,2
2nd RAINY SEASON	-0,5	-0,1	0,3	0,6	-0,1	0,3	-0,3

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ANNUAL CYCLE PHASES	MAIZE	SORGHUM	PLANTAIN	CASSAVA	COTTON	SESAME	BEANS
DRY SEASON	0,1	0,4	-0,2	0,4		0,0	0,0
1st RAINY SEASON	0,1	0,2	0,3	-0,5		0,0	0,2
VERANILLO	0,2	0,3	0,0	0,2		0,5	-0,3
2nd RAINY SEASON	0,0	0,0	0,5	-0,2		0,5	-0,4

During the Veranillo de San Juan, a minor direct relationship was detected to the northwest and there were even precipitation nuclei in those sites where the relationship wasmore pronounced(***r***>0.5).

For sorghum, the relationshipof PI oscillations during the Veranillo de San Juanand thesecond rainy season with YIs is practically nonexistentthroughoutthe department (Figure 6). Only in the case of the dry seasonand the first rainyseason were there sectorswherethe relationship could be perceptible (***r***valuesbetween -0.5and -0.2and between 0.2 and0.5).

Regarding to plantain, there was aweak, direct relationship (***r*** = 0.2to 0.5)betweenthe YIs and the PIs during both rainy seasons for a large part of the department, with the presence of several precipitation nucleiwherethe relationship was stronger(***r***>0.5) (Figure 6). During the dry season, no relationship was observed between PIs and YIs for most of theterritory, whereas a

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direct relationship was perceptible during theVeranillo de San Juan in western Atlántico, witha precipitation nucleus towards the southwestin which the relationship between the YI and PI was quite evident.

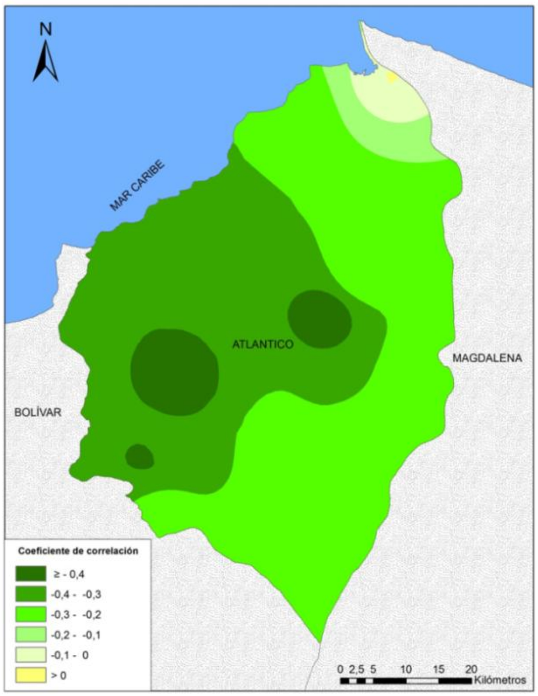

Figure 5. Spatial distributionof correlation coefficients between the series of ONI values and that of PIs from different partsofthe departmentof Atlántico.

For sorghum, the relationshipof PI oscillations during the Veranillo de San Juanand thesecond rainy season with YIs is practically nonexistentthroughoutthe department (Figure 6). Only in the case of the dry seasonand the first rainyseason were there sectorswherethe relationship could be perceptible (***r***valuesbetween -0.5and -0.2and between 0.2 and0.5).

Regarding to plantain, there was aweak, direct relationship (***r*** = 0.2to 0.5)betweenthe YIs and the PIs during both rainy seasons for a large part of the department, with the presence of several precipitation nucleiwherethe relationship was stronger(***r***>0.5) (Figure 6). During the dry season, no relationship was observed between PIs and YIs for most of theterritory, whereas a direct relationship was perceptible during theVeranillo de San Juan in western Atlántico, witha precipitation nucleus towards the southwestin which the relationship between the YI and PI was quite evident.

On the cassava, the same figure also shows that dry season PIs in most parts ofthe departmenthavea weak relationshipwith YIs. Inotherseasons, this relationship was even weaker and only a few isolated precipitation nuclei, wherethe relationship was more pronounced, could be observed. For example, for the first rainy season there was one precipitation nucleus in northern Atlántico and twonucleiwithstrong inverse relationships in the central partof the department, whereas for the Veranillo de San Juan a relationship between PIs and YIs was observed in the central-west part of the department.

As regards the sesame, Figure 6 shows the existence of small groups scattered throughout much of the department that showed a weak correlation(***r*** = -0.2 to+0.2)betweenthe interannual variability ofseasonal PIs andinterannualfluctuations of YIs during the dry season. During both first and second rainy seasonsand theVeranillo de San Juan, there was a weakrelationshipbetween both variablesinlarge areas throughout the department, except sectors of northern and central Atlántico duringthe first rainy season; sectors of northern, western, andsouthwestern Atlántico during the second rainy season; and sectors of northern andsoutheastern Atlántico during the Veranillo de San Juan. The relationship is stronger (***r***>-0.5) in precipitation nuclei observed in southern, eastern, and western Atlántico during the firstrainy season;central and extreme southern Atlántico during the second rainy season; and central, southern, and western Atlántico (covering a larger area) during the Veranillo de San Juan.

It was alsopossible to infer thatbean yieldsare insensitiveto variations in the PIs ofthe different seasonsthroughout the department of Atlántico, showing mostly very low correlation coefficientvalues. Onlythe variability of rainy season PIs ofrelatively large areas in northern and eastern Atlántico showed aweak relationshipwith YIs.

In the case of cotton, the relationship between dry season PIs and YIs was practically inexistent throughout the department (Figure 6). During the second rainy season, the PI affected the YI to some extent in one sector of southern Atlántico.

Conclusions

The analysis of the climate-agriculture relationship in the department of Atlántico indicates that, although farming has been technified with the use of irrigation systems, the planting of many of the

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mainagriculturalcropsof the region is scheduled depending on the annual precipitation cycle, which directly exposes the sector tothe ravagesofclimate anomalies.

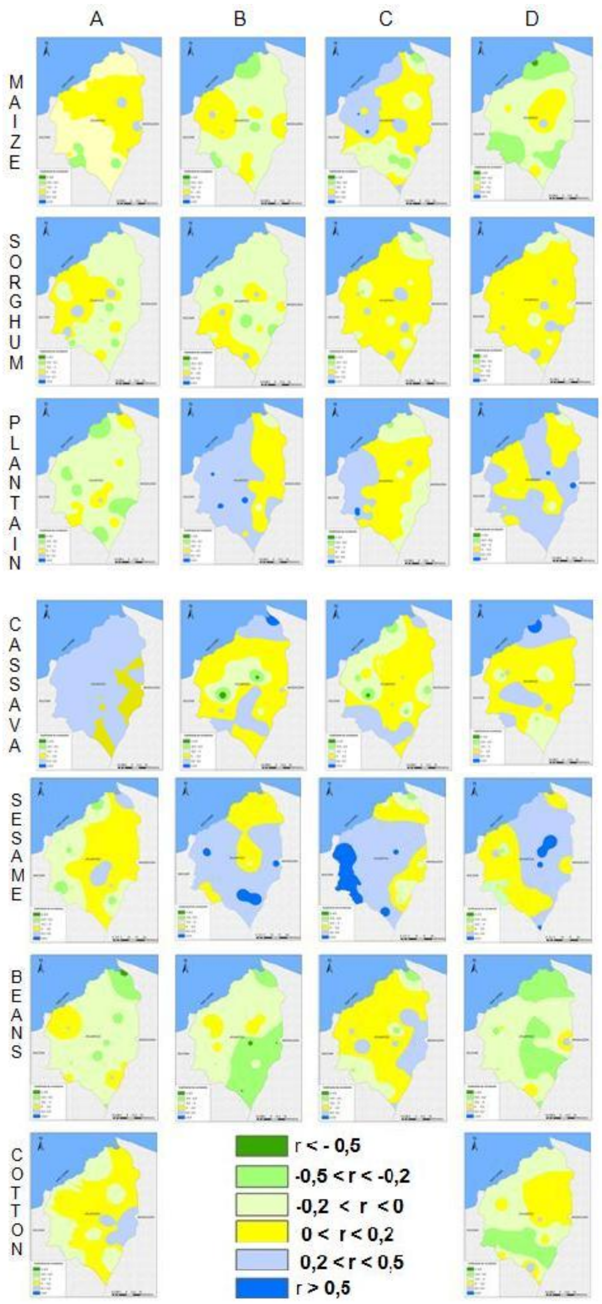

Figure 6. Spatial distribution ofthe correlation coefficients (r) with a 1-year time difference between the YIs ofdifferentcrops and the PIs corresponding tothe dry season(A), first rainy season (B), Veranillo de San Juan(C), and second rainy season (D). Cotton is grown inthe secondrainy season and harvested in the subsequent dryseason.

The analysis ofthe seriesof monthly PIs evidenced the recurrence of extreme anomaliesin precipitation, which, when compared with the corresponding ONIseries, clearly corresponded to the warmphase(El Niño) andcold phase (La Niña) of the ENSOcycle. Despitethe obvious connection, the correlation coefficientscalculated forthe smoothed series of monthly PIs as compared with the ONIserieswere relatively low. Notwithstanding,an inverse relationship was perceptible(***r***<-0.4) in central-western Atlántico, wherethe response ofregionalprecipitation to events occurring in the Pacific Ocean was more obvious.

TheEl Niño andLa Niña phenomena were found to be largely responsible for the interannualoscillations in precipitation in different regions of the department of Atlántico. UnderEl Niñoconditions, below-normal amounts of precipitation were recorded in the region and, under La Niñaconditions, above-normal amounts of precipitation occurred. The effect of this increase in rainfall in Atlántico, together with the heavy rains that fell in the Upper and Middle Magdalena river basin also as an effect of La Niña, caused severe flooding throughout the entire basin—a factor that was not included intheprecipitation seriesanalyzedin herein.

Recurringclimaticanomaliesassociated with the effectsofEl Niño andLa Niñainthe region affect the department’s agriculture sector follows: as a result of La Niña, the heavy rainsflood croplands and cause significant yield losses and, as a result of El Niño, the deficit in precipitation and ensuing drought reduce crop production. However, not allcropsrespond in the same wayto phases of extreme climate.

Sesame and plantain increased their yields with above-normal amounts of precipitation(usually under La Niña) during theVeranillo de San Juanand both rainy seasons. Above-normal amounts of precipitation during the dry season have a positive impact on cassava yields. Meanwhile, maize yieldsincreasedif above-normal amounts of precipitation fell during the Veranillo de San Juan, but decreased if above-normal amounts fell during the second rainy season. Bean yields decreased with above-normal amounts of precipitation during the first and second rainy seasons, but increased with above-normal amounts during the Veranillo de San Juan. Cotton yields decreased with above-normal amounts of precipitation during the second rainy season.

Sorghumshowed noperceptibleresponseto anomaliesin precipitation.

The aforementioned findings indicate that the extreme phasesof climate variabilityassociated withEl Niño andLa Niña do havea significant impact on the agricultural productionof the departmentof Atlántico in Colombia.

One way to reducethis negative impactis to adapt regionalagricultureto the abnormal conditionsimposed by these recurrent extreme phases. However, basic knowledge necessary to further concrete proposals and actions to achieve this adaptation is lacking or limited. There is a limited understanding of the region's climate and the role played by orographic systems in its definition (for example, what underlies the differential spatial distributionof precipitation inthe region or why there is a dry nucleus in the Repelonarea). In addition, althoughstatisticson agricultural production are available, these are incomplete and consolidated at a departmental level. Nodetailed information exists on agricultural production per municipality. Furthermore, the understanding of the relationship between climate andregional crops is usually restricted to the ranges of temperature and humidityrequiredfor each. No information is available on how to respond to water stressor the resistanceof each species orvariety to deficient or excess moisture.

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