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# Rainfall Patterns Associated with the Oceanic Niño Index in the Colombian Coffee Zone

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**Abstract**

Farming is one of the most water-demanding activities in the world. In Colombia, a coffee crop planted with rust-resistant varieties requires between 1500 and 1800 mm of annual rainfall. Crop phenological stages such as flowering and production are determined by the behavior and amount of rainfall. The aim of this study was to evaluate the effect of the Oceanic Niño Index (ONI) on the cumulative rainfall for the Colombian coffee zone. Simple correlations between the Oceanic Niño Index and cumulative monthly rainfall level were analyzed. The correlation coefficient and the p-value were determined for each station analyzed and for each month of the year. The objective is to determine if the ONI could be used in a forecast by analogy—an old but effective method to make decisions in agriculture—and mainly to define adaptation strategies. We found that the relationship between the ONI and cumulative rainfall did not have a homogeneous behavior throughout the country. There are different behaviors, and those depend on the seasons and regions. ONI has a high impact on the rainfall of the dry seasons in the center and sometimes in the south of the country. However in the north, there are no significant effects of this index. It means that other indices should be used to quantify the effect of El Niño and La Niña on the rainfall of the Colombian coffee zone or, on the other way, the use of other climate variability triggers, such as the Pacific Decadal Oscillation or the North Atlantic Oscillation.

**Keywords:** climate variability, coffee, rainfall, ENSO, Colombia

## 1. Introduction

Colombia is one of the worldwide leading producers of coffee, and its economy is highly dependent on this commodity. In this country, the coffee yields are largely determined by the amount of precipitation (Ramírez et al., 2010), such as in any other rainfed crops. According to Jaramillo (2005), a good site for a coffee crop should have at least 1500 mm of annual rainfall. However, besides the amount, distribution of the precipitation throughout the year is also important in coffee production. For example, dry seasons are crucial to achieving high coffee yields. This happens because, in equatorial regions, anthesis depends on the presence of water stress (Drinnan & Menzel, 1994; Camayo et al., 2003). Coffee plants respond to dry season in the same way as any other ones, that is to say by changing their hormonal balance, producing more abscisic acid (Chapin III, 1991). The excess of this phytohormone in the flower buds leads to a high rate of anthesis (Florez et al., 1996). Immediately after the anthesis, coffee plants require enough water in the soil to support the fruit filling. So, the highest yields are produced when the dry and rainy periods are in sync with the production stages (Arcila et al., 2007). In that way, a prolonged dry period can also affect the fruit filling if it happens during this stage of the crop. In contrast, prolonged excess water periods can affect the development of flowering, crop health, and cause a loss of soil and nutrients (Ramírez et al., 2010; Jaramillo et al., 2011b; Ramírez et al., 2014).

In Colombia, especially in the Andean region, rainfall mainly depends on two systems, the Inter-Tropical Convergence Zone (ITCZ), and the El Niño Southern Oscillation (ENSO). The ITCZ can be identified as a tropical belt of deep convective clouds, moving through the year from one hemisphere to another one following the apparent moving of the Sun (Waliser & Gautier, 1993). It means that the zone of most intense rainfall in the Earth migrates towards a hemisphere that warms relative to the other (Schneider et al., 2014). Over the North of

South America ITCZ migrates between 9°N and 5°S (León et al., 2000). It explains the two rainy seasons and two dry seasons in the central (3°N–7°N) and the southern (1°N–3°N) coffee regions. While in the northern coffee region there are only two seasons, the dry and the rainy season. ENSO is a coupled ocean-atmosphere phenomenon known to have associated climate effects in many regions around the world (Rosenzweig, 2001). The oceanic part of the event is associated to the fluctuation of the equatorial Pacific surface temperature and the atmospheric part is related to changes in the pressure and the wind pattern along the Pacific basin. ENSO has two phases, El Niño and La Niña. El Niño is the positive phase, characterized by the warming of the equatorial Pacific surface, and the weakness and change in the trade winds flow; while La Niña is the contrary, a water surface cooling and the strengthening of the trade winds (Cane, 2001). Several authors point out that in the Colombian coffee growing zone rainy years are associated with La Niña and dry years with El Niño (Ramírez & Jaramillo, 2009; Poveda et al., 2001; Poveda, 2004).

While the ITCZ explain the inner year rainfall variation, ENSO determines the fluctuation in annual total precipitation between years (Pena et al., 2011). Although there are several indices and variables to characterize the ENSO, currently, the Oceanic Niño Index (ONI) is widely used by decision makers and stakeholders for crop and market planning in Colombia. It is used as an indicator of the prevailing ENSO condition (El Niño, Neutral or La Niña). The ONI is defined as the anomaly of the surface temperature of the Pacific Ocean in the region known as El Niño 3.4 region (5°S–5°N; 170°W–120°W) with respect to a defined reference period (1971-2010). The indicator is easily interpreted according to Table 1. The aim of this study is to establish the relationship between the ONI Index and cumulative rainfall in different weather stations along the Colombian coffee zone. In spite of the index is easy to use, it is important to know where and when it can be used as a screening tool that enables proper scheduling of coffee crop management tasks such as crop establishment, fertilization, and health management, among others, such as suggested Nageswara et al. (2007).

Table 1. ENSO prevailing condition according to Trenberth (1997) and Tootle et al. (2008)

| ONI Value | Condition |
|---|---|
| Three or more consecutive months with values above 0.5 | El Niño |
| At least one month with values between -0.5 and 0.5 | Neutral |
| Three or more consecutive months with values below -0.5. | La Niña |

## 2. Method

### *2.1 Weather Stations*

77 weather Stations, representatives of the Colombian coffee zone, with over 20 years of data on a daily scale were selected; they were located between the Sierra Nevada de Santa Marta at 11°N and the Nariño department near the equator (1°N). Daily precipitation data were accumulated at monthly scale to get a new database where each year is represented by 12 values (January to December).

### *2.2 Analysis*

Time series of the Oceanic Niño Index (ONI) was taken monthly from 1950 to 2010. It was extracted from the database of the National Oceanic and Atmospheric Administration of the United States (NOAA). Once the information regarding cumulative rainfall on a monthly basis and the Oceanic Niño Index (ONI) was consolidated, the series on a monthly level were related by using linear regressions. These are used to determine the correlation coefficient between these two variables for each month. Specifically, a correlation coefficient for each of the 12 months of the year and the significance level (95% of confidence) was obtained using SAS software version 9.3.

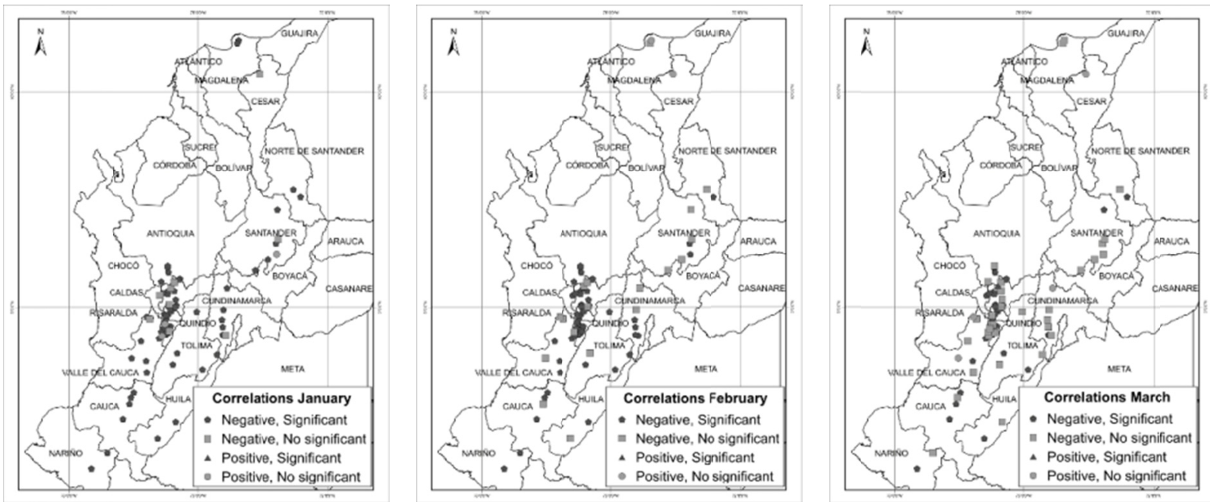
### *2.3 Characterization of the Correlations*

The spatial characterization of the relation between ONI and cumulative rainfall was done by plotting correlation coefficients (r) for each station on the map of Colombia. Correlation and significance levels were represented with points of different shades and shapes. Four basic groups were generated: a) Significant negative relation, b) Non-significant negative relation, c) Significant positive relation, and d) Non-significant positive relation. A positive relation means that during El Niño events there is more precipitation than under Neutral conditions, or in other words, during La Niña there is less precipitation than during Neutral conditions. This analysis was done for each month of the year in order to infer the spatial and temporal behavior of the ENSO effect on the precipitation of the Colombian coffee region. The procedure was performed using the ArcGIS software version 10.1, by using the Magna-Sirgas coordinate system with origin center in Bogotá, Colombia.

## 3. Results

### *3.1 January to March*

In general, ONI has an opposing relationship with rainfall this quarter, in the Colombian coffee region, which means that La Niña brings excessive rainfall while El Niño is related to dry conditions. However, there are some locations, all of those in the North of the country (Magdalena and Cesar areas), where the relation between ONI and rainfall is positive in January and near-zero in February and March. In those places, the ENSO's effect on the rainfall, described by using ONI, is lesser than in the rest of the region. As mentioned above, correlations are mainly negative (significant and non-significant) in the central and south coffee areas. As a generalized effect, the significant correlations turn into non-significant correlations as the year goes on, so there are more locations with negative and substantial correlations in January than in March (Figure 1 and Figure 5).

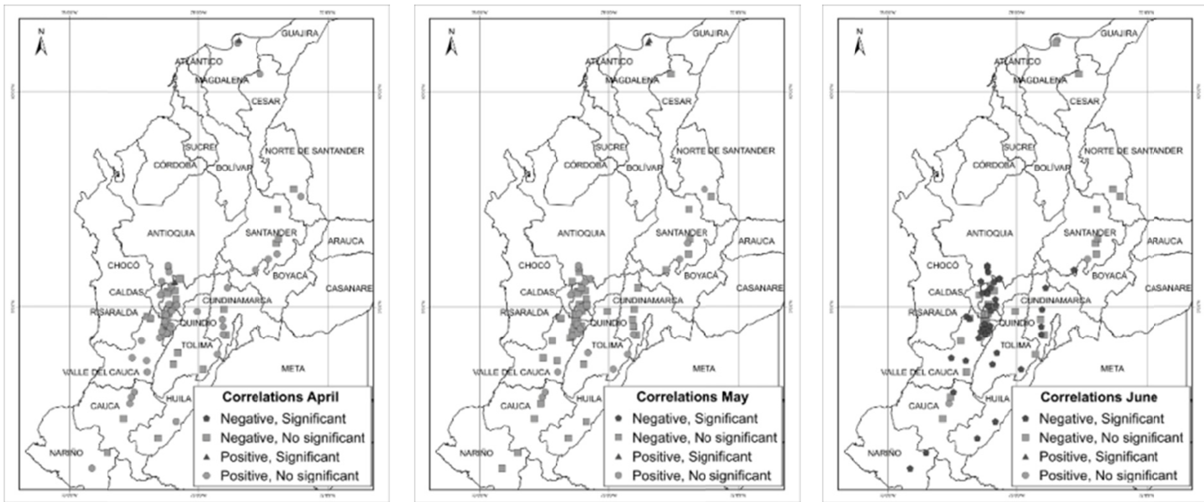



a. b. c.

Figure 1. Monthly correlation between the ONI and cumulative rainfall in the weather stations of the Colombian coffee zone, a) January b) February, c) March

### *3.2 April to June*

In general, the rainfall in the second quarter is not related or poorly related to the Oceanic Niño Index. In April and May, only 6 percent of the analyzed locations (Jirocasaca–Magdalena, Santa Helena–Caldas, Paraguaicito–Quindío, Albán–Valle del Cauca–Cuatro esquinas–Caldas) had significant (and negative) correlations between the ONI and the precipitation. This behavior where five stations, spread around the country, exhibit a significant relation between ONI and precipitation put into consideration the local effect of these phenomena. The effect of ENSO, described by using ONI, increased between April and June. For this reason, the percentage of stations where the correlation is significant increased from 6 percent in April to 45 percent in June. The weather stations where there is a high relation in June are located mainly in departments of Antioquia, Caldas, and Risaralda (center of the country). During this season, the precipitation of some stations is positively related (not significant) with the ONI, mainly during April. As a particular case, two stations (Jirocasaca and La Victoria) in the north of the country showed significant correlations between the ONI and rain, 0.37 and 0.26 during May (Figures 2 and 5).

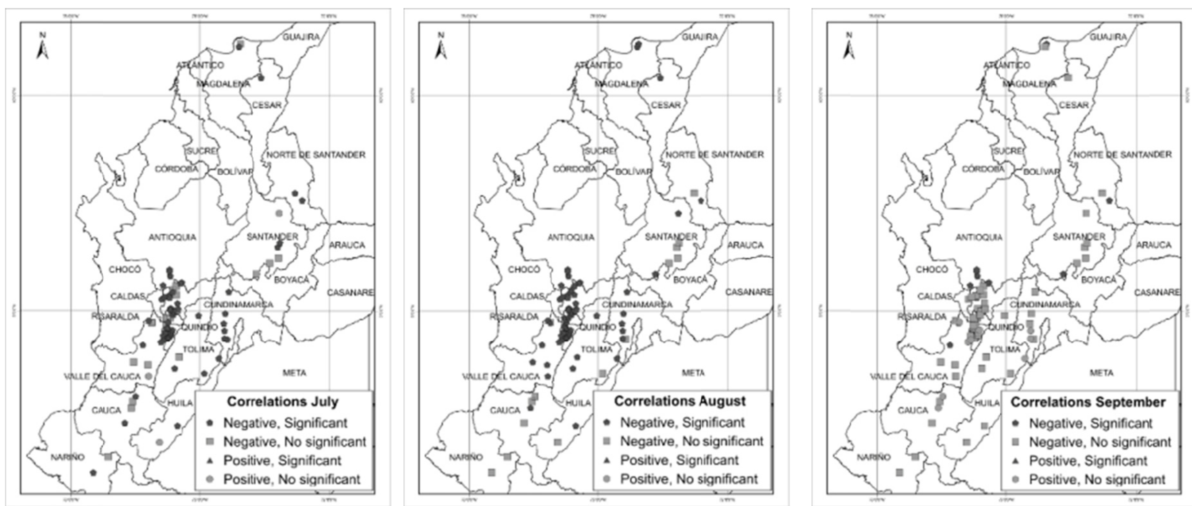



a. b. c.

Figure 2. Monthly correlation between the ONI and cumulative rainfall in the weather stations of the Colombian coffee zone, a) April b) May c) June

*3.3 July to September*

In this quarter, in most of the analyzed locations, the rainfall has a negative and significant relationship with ONI, specifically in the center of the country. In the northern zone of Colombia, the correlation between the ONI and cumulative rainfall did not show a definite tendency; some of the stations show significant correlations for a month, but in the next, the correlation is no longer significant. The significance of the relationship grew through the time, and for this reason, 56 of the locations used in the analysis did not show a significant correlation between cumulative rainfall and the ONI in September. However, in July, 58 of the sites showed significant correlations between ONI and precipitation. The highest correlations between the ONI and precipitation were concentrated in the departments of Antioquia, Caldas, Quindío, Risaralda, and Valle del Cauca (Figure 3 and Figure 5).

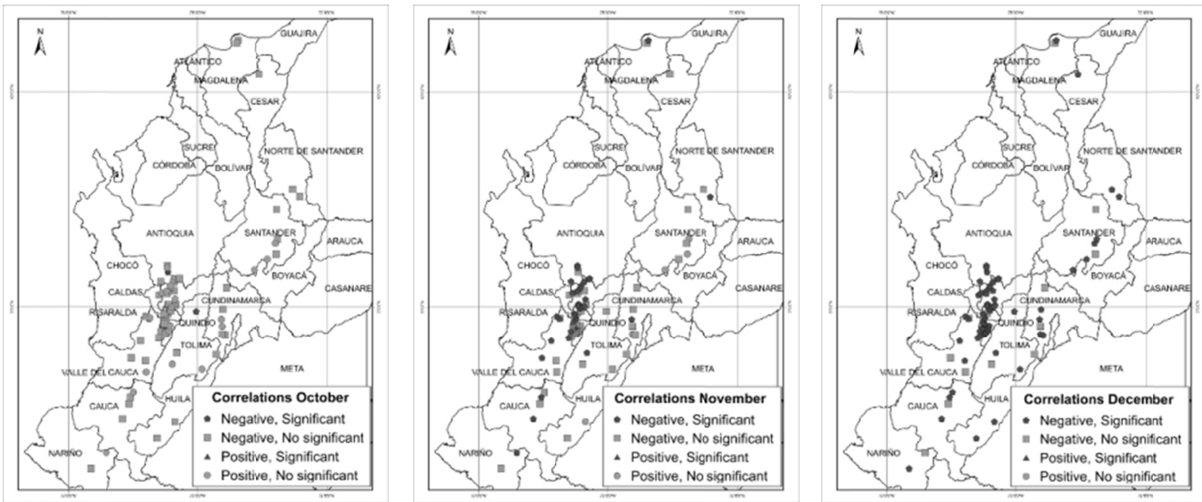



a. b. c.

Figure 3. Monthly correlation between the ONI and cumulative rainfall in the weather stations of the Colombian coffee zone, a) July, b) August, c) September

*3.4 October to December*

In October, changes in the values of the ONI do not significantly affect the rainfall values (correlation values below -0.32 for 74 weather stations in the network). In the northern zone of Colombia (Latitudes higher that 7°N), correlations are not significant in October. For November, the correlations between the ONI and cumulative rainfall were significant for 31 weather stations in the network. In December, the correlation between the ONI and cumulative rainfall showed higher correlations than in October or November. in December, 79 percent of the locations showed correlations above -0.32, which was significant (Figures 4 and 5).




a. b. c.

Figure 4. Monthly correlation between the ONI and cumulative rainfall in the weather stations of the Colombian coffee zone, a) October, b) November c) December

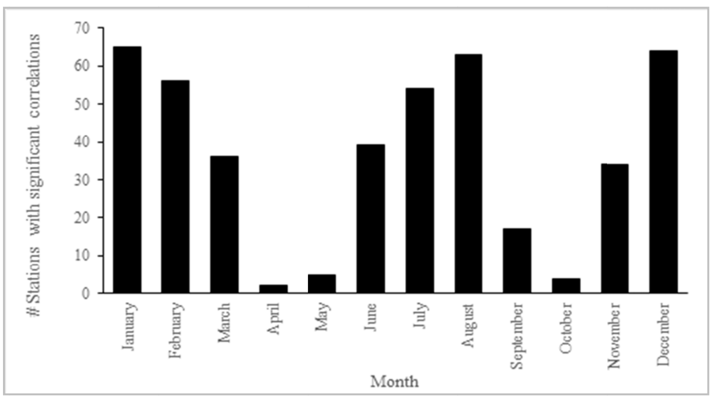



Figure 5. Number of stations with significant correlations between the oceanic El Niño index and cumulative rainfall for each of the months of the year

## 4. Discussion

In the context of climate change, the strategy for crop adaptation in Colombia, described by Ramirez and Khoury (2013), has an important component based on the knowledge of the actual climate patterns. This meteorological information at a local scale is used to assess the potential impacts of climate change and climate variability. The information is used through the forecast by analogy (Glantz, 1996), an old method that is widely used to make decisions not only in agriculture but also in other economic activities. In Colombia, the methodology is mainly focused on the ENSO effects. In that way, an in-depth knowledge of the effect of ENSO on the climate is needed, as well as the effect of the climate scenarios on the crop yields. However, some uncertain sources are identified; the first source is related to the index used to describe the conditions over the Pacific Ocean. Therefore, the question is if the ONI is the correct index to do a correct characterization of the ENSO effect on the precipitation. The second factor is related to the real effect of the ENSO over the rainfall in the coffee region. It could be more complex because it implies understanding if some generalizations could be accepted, and it is related to a good understanding of the ENSO indices on the local precipitation. A common generalization, for example, is that El

Niño causes dry conditions in the coffee-growing region while La Niña has a contrary effect.

As a response to those questions, some authors have demonstrated the effect of ENSO on specific seasons rather than on the entire year (Pena et al., 2014; Ramirez & Jaramillo, 2009). However, according to the results, the ONI effect is concentrated on some seasons (Figure 5) as well in some locations. This special climate response to ENSO has been reported by other authors (Schmidt et al., 2001). The spatial behavior of the rainfall anomaly (by ENSO) is not a surface; there are hot spots, and they cannot be detected by Global Climate Models (GCM). The only way to detect them is by good sampling (well-distributed weather networks), and for this reason the number of weather stations in the coffee-growing zones has been increasing in the last three years.

In Peru, the impacts of rainfall during El Niño and La Niña have the same localized behavior as in the Colombian coffee growing region, but the Southern Oscillation Index (SOI) has been used to make the ENSO characterization. According to these authors, the variability of the Pacific Ocean does not explain the whole rainfall variability in Peru; thus, other climate variability generators, such as the Tropical Atlantic Ocean, must be used to understand what is happening in that region (Lavado, 2014). It could mean that the non-homogeneous relationship between the index and the precipitation along the country is not related to the used index. The high complexity related to the dynamic climate factors can mostly be explained by the orography of the coffee growing region conditions. In this case, the solution is to check for the effect of some other climate variability triggers. For example, in Brazil, a country belonging to the Atlantic Basin, and specifically in the northeast of this country, the climate is modulated by the changes in the sea surface temperature in the subtropical North-Atlantic (Uvo et al., 1998). This coincides with the results that show that the north of the Colombian coffee growing zone, influenced by the Atlantic Ocean (Caribe Sea), exhibited a lower correlation with ONI (Figure 1 to Figure 5) and ENSO, as showed by Pena et al. (2014).

In this case, the problem is not the non-relation of the ONI with the precipitation but the lack of effect of the ENSO on the coffee growing region, or at least the not continuous effect along the year and along the surface. Meza et al. (2003) reported a good fit of ENSO-driven crop productivity forecast in Central Chile, where the effect of ENSO on precipitation and evapotranspiration is greater than in the rest of the country. According to Stern and Sterling (1999), it is logical that an ENSO-based forecast can be used in Chile because Chile is located in the Pacific Basin and because there is a high probability that in this country, as in Peru, Ecuador, Australia, and the Pacific Islands, precipitation and the air temperature are connected to ENSO. Another identified problem is that coffee is a perennial crop, and for this reason, the decision makers need high certainty throughout the year and across the country in the case of policymakers. However, the results show that in the Andean region (south and central coffee growing season), the effect of the ONI on the precipitation is higher just in the dry seasons when the ITCZ is far away from that region. On the other hand, the precipitation of the north of the coffee growing zone does not have a strength relation with the index. Those results show the necessity of finding climate variability generators in the north of the country and other indices explaining the variability in wet seasons in the central and southern zones. The problem is that the indices as the ONI should be predictable (Stern & Easterling, 1999).

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