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Oceanic Niño Index as a Tool to Determine the Effect of Weather on Coffee Plantation in Colombia

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

The aim was assess the reliability of the Oceanic Niño Index (ONI) as appropriate index to adjust early weather warnings for the coffee sector in Colombia. The study was conducted in the National Coffee Research Center (Cenicafé), Manizales, Colombia between January 2013 and June 2014. Simple correlations between ONI and number of rainy days, at monthly scale, were done. Correlation coefficients (R) and P-values for every month and station were calculated, and twelve maps (one per each month) showing if the correlation is positive or negative and the significance were used in order to determine the ONI effect´s on rainfall at spatial and temporal scales. The results show that the effect of the ONI on the number of days with rain is differential and depends on the area being analyzed. The effect is similar in the central and southern coffee regions, whose behavior is totally different from the coffee zone of the Sierra Nevada de Santa Marta (northern coffee zone). In the north, the ONI has a positive relation with the number of days with rain in the first half of the year, similar to the effect on the South Eastern of the U.S.A. In conclusion, ONI cannot be used widely (time and space) as an index to adjust early warning systems in the coffee growth zone in Colombia.

Keywords: ENSO; climate variability; coffee crops; rainfall; Colombia.

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1. INTRODUCTION

According to [1], because the weather can limit the survival of plants [2], the concept that [3] had restricted to arid and semi-arid tropical regions can be extrapolated and, thus, ensure that climate variability is and will remain the main source of variation in the numbers of agricultural production worldwide. In fact, according to the hypothesis of [4], the origin centers of the plants are explained by the presence of appropriate physiological characters to grow, survive and reproduce in the environment provided by those areas, as stated more recently by [5]. However, in the case of plant production systems, the matter may be even more complex since, in addition to the minimum conditions of survival, the environment should provide conditions that constitute the highest yields.

The coffee production system (*Coffea arabica* sp), in turn, is highly dependent on the availability of rainwater for the development of the flowering and fruit filling stages [6]. Overall, this crop requires between 1,400 and 2,900 millimeters of annual precipitation to meet its water needs [7] and the alternation of dry and rainy seasons to set high productivity. Alternating periods explains the floral opening of coffee [7-10]. Therefore, abnormally rainy periods during usually dry seasons, affect negatively the flowering, which results in major changes in the temporal dynamics of the anthesis. Consequently, this results in poor fruit quantity and quality as well as in less temporal concentration of the coffee crop generated by flowering [11,12]. The complexity can be even greater when farming systems are not populations but communities in which the organisms that grow on the surface determine the productivity of the crop species [13]. In the case of coffee, the proliferation of pests and diseases is highly correlated with the number of days of precipitation [14]. According to these authors, the vast majority of coffee pathogens require rain to disperse, germinate and penetrate into the plant. Therefore, infective processes can rise steeply under high humidity conditions, while pests, specifically coffee berry borers (*Hypothenemus hampei* Ferrari.), leaf-miners (*Leucoptera coffella* Green) and red mites (*Oligonychus yothersi* McGregor), require water deficit conditions and high temperatures to set their maximum infestation potential.

It is clear that the weather has a significant effect on production, not only on coffee, but on any crop. Thus, early warning mechanisms that seek ample time to change farming practices according to prevailing weather conditions have been developed in order to mitigate the negative effects of weather and to strengthen its positive effects on coffee production. According to [15], an effective early warning system, reducing the risk of crop failure, needs to be related to a high certainty of its modules. The first module considers the relationship between the variable of interest (associated with the presence of pests, diseases or production parameters) and the elements of weather while the second module considers a projection, forecast or prediction of climatic variables that allow the time margin required to plan and carry out the changes on the crop technical itineraries.

In Colombia, especially in the Andean region, the relation between El Niño Southern Oscillation -ENSO- [16] and the climate is seized [1,12,17-26] in order to design and define the changes in certain farming activities. Although, until recently, the two extreme phases of ENSO, i.e., El Niño and La Niña, were defined with respect to different indices, including Southern Oscillation indices, Surface Temperatures and Mean Sea Levels in different points of the Pacific Ocean [22,27], currently, the use of the Oceanic Niño Index -ONI- as an indicator of the prevailing condition of ENSO (El Niño, La Niña or Neutral) is widespread. ONI is defined as the surface temperature anomaly in the Pacific Ocean in the region known as El Niño 3.4 (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.

Despite the ease of interpretation of ONI, according to the most recent work for the zone of influence of coffee cultivation [1,17], the relation between this index and the rainfall variable is not generalizable. For example, even the accumulated rainfall of some coffee region sites is not related to this index. For this reason, the objective of the study is to determine the correlation between the variable number of days with rain and the Oceanic Niño Index for the Colombian coffee zone, with the aim to determine those areas in which there is a relation between the index and the behavior of the variable rainfall, and those areas where the behavior of the variable is not explained by the ONI.

Table 1. ENSO prevailing condition according to [28,29]

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. METHODOLOGY

2.1 Datasets

For its effect on the coffee production system (harvest distribution, fruit filling, sowing, etc.) the variable analyzed was the number of days with rain per month. To determine this variable, the historic daily rainfall data were collected. Rainfall dataset come from the weather stations of the coffee climate network, with over 20 years of data on a daily scale, located between the Northern Coffee Zone, in the Sierra Nevada de Santa Marta, more than 10 degrees north la|titude, and the Colombian Southern Coffee Zone near the Equator, in the Nudo de los Pastos (Table 2). In this case, a rainy day was determined as that record of daily precipitation equals or exceeding 0.1 mm; subsequently, these events were counted and totaled on a monthly basis. The historic series of the Oceanic Niño Index (ONI) was collected monthly from 1950 to 2010. This series was extracted from the database of the National Oceanic and Atmospheric Administration of the United States (NOAA).

2.2 Analysis

Once the information of the number of days with rain on a monthly basis and the Oceanic Niño index (ONI) was consolidated, the series were filtered on a monthly level to determine the correlation coefficient between these two variables for each month; i.e., a correlation coefficient for each of the 12 months of the year was obtained. Additionally, the significance of the correlations obtained with P = .05.

The degree of correlation between the ONI and the analyzed climatic variable was plotted on a map of Colombia using circles of different hue and size. For a correct interpretation of the maps, remember that the high values of the ONI (greater than 0.5) are related to El Niño and the low values (below -0.5) are related to La Niña, that is why it is possible to have positive and negative correlations. Significant positive correlations are associated with sites where El Niño generates increased number of days with rain, while negative correlations mean the exact opposite.

Pentagous and triangles represent high absolute (negative) correlation values, i.e., places where ENSO strongly modulates the behavior of the elements analyzed. In contrast, squares and circles denote locations where the effect of ENSO on the analyzed variable is minimal or sites where the correlation is positive. This analysis was done for each month of the year, so that it is possible to infer the temporal behavior of the effect of ENSO on rainfall of the Colombian coffee zone throughout the year.

3. RESULTS AND DISCUSSION

3.1 January to March

In general, the largest absolute correlation values between the ONI and the number of days with rain occur in the central and the south coffee zones. In fact, the stations where the ONI has greater effect on the studied variable (lower correlations - 0.56) are located in the Cauca River Basin, between the Western mountain chain and the western slopes of the Central mountain chain. To the north of the Colombian coffee zone, the correlations begin to reduce their absolute value. For example, in the Pueblo Bello station (Pueblo Bello - Cesar), located in the northern Colombian coffee zone, the correlation between the number of days with rain and the Oceanic Niño Index is positive and significant in some months, contrary to the rest of the country, where the correlations are negative. This shows that in this area the number of days with rain in El Niño presence tends to increase. In the other stations of the northern zone, located in the department of Magdalena, (Jirocasaca and La Victoria), there is no relation between the ONI and the number of days with rain (correlations close to zero) (Fig. 1).

On the other hand, there is a reduction in the effect of the ONI on the number of days with rain as the first quarter of the year (January to March) advances, which is more evident in the central-northern coffee zone, especially in southern Antioquia, Caldas, Quindio, Risaralda, Cundinamarca and Santander, where in some stations the correlations are near zero in March.

As an exception, in Norte de Santander the ONI effect on the number of days with rain raises through the first quarter of the year (Fig. 1).

3.2 April to June

Unlike what happens in the first quarter of the year, when the levels of the relation between the ONI and the number of days with rain decrease as time passes, between April and June the relation between the ONI and the weather variable is incremental in most analyzed stations. It should be noted that during April and May the lowest correlations of the first half of the year occur in the central and southern coffee regions. In April, for example, the relation between the ONI and the number of days with rain that had generally been negative showed positive for more than 30% of the stations analyzed. However, although these relations were positive, none was significant and all were close to zero, showing that during April and May, similar to what happens in March, there is no relationship between what happens with the ONI and what happens to the variable under analysis in most of the Colombian coffee zone. The stations of the north zone of the country maintain positive correlations, although not significant, between the ONI and the number of days with rain, showing that in this region, the effect of the ONI on the variable under analysis is minimal (Fig. 2). The incremental effect of correlations, which was seen in the first quarter of the year in Norte de Santander is no longer perceived, and there are correlations near-zero between April and May; in June the relation between the ONI and the number of days with rain is greater than in April and May. However, the relation of this quarter of year is lower than the relation of the first quarter.

3.3 July to September

The relation between the ONI and the number of days with rain between July and September is high in most of the analyzed stations, especially during August. However, in this month there are a couple of stations that do not show significant correlations between the ONI and the number of days with rain (Timaná and Gigante in Huila). In this quarter of the year, correlations between the ONI and the weather variable under analysis are negative and significant at the stations in the north of the country, where in the previous quarters of the year there were positive correlations. In the north, the absolute value of the correlation increases with latitude. It also happens in March during the first quarter of the year, in September the relation between the ONI and the number of days with rain is very low. Particularly, it is necessary to note that in July, when most of the coffee area has high relations between the two variables analyzed, four of the stations in the south showed no significance in the correlation between the ONI and the number of days with rain. Only the Manuel Mejiastation (El Tambo - Cauca), Ospina Pérez (Consacá - Nariño) and La Trinidad (Piendamó - Cauca) had significance (Fig. 3).

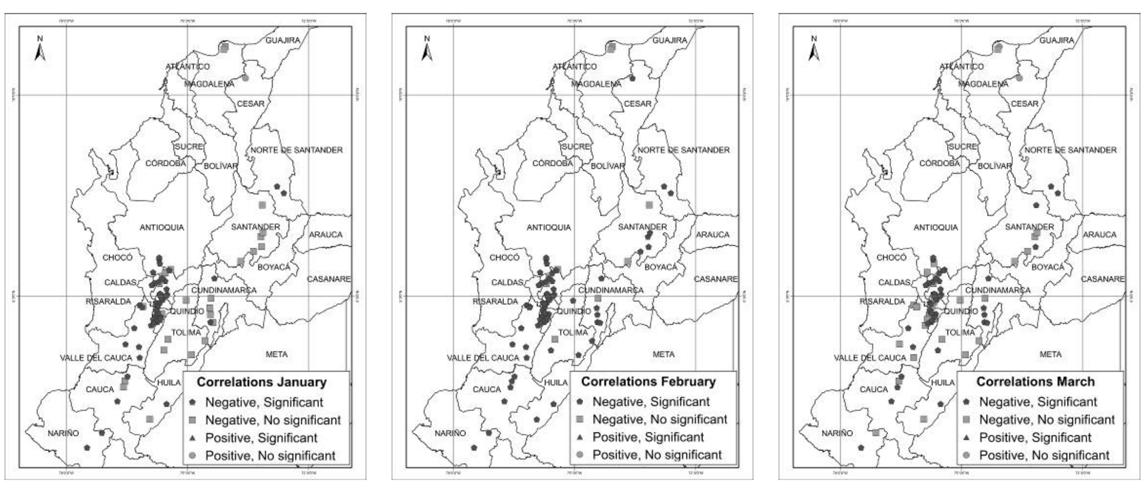

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Fig. 1. Monthly correlation between the ONI and the number of days with rainfall in the weather stations of the Colombian coffee zone, a) January b) February, c) March

Table 2. Weather Stations of the coffee climate network used in the analysis

Station name	Department	Latitude (N)		Longitude (W)		Altitude	Historical series	
		Degrees	Min	Degrees	Min	m	Start	End
Ospina Pérez	Nariño	1	15	77	29	1603	1953	2010
El Sauce	Nariño	1	37	77	7	1609	1982	2010
Conc. Desarrollo	Huila	1	57	75	56	1080	1986	2010
Jorge Villamíl	Huila	2	20	75	31	1420	1955	2010
Manuel Mejía	Cauca	2	24	76	44	1735	1953	2010
La Trinidad	Cauca	2	45	76	35	1671	1980	2010
Mondomo	Cauca	2	54	76	33	1380	1983	2010
Inst. Técnico	Cauca	3	1	76	29	1058	1951	2000
Campanella	Valle	3	29	76	11	1512	1976	2010
La Montaña	Tolima	3	33	74	54	1296	1956	2000
El Limón	Tolima	3	40	75	35	888	1971	1996
La Selva	Valle	3	45	76	12	1805	1980	2010
Julio Fernández	Valle	3	49	76	32	1381	1954	2010
Luis Bustamante	Tolima	3	54	74	34	1616	1964	2004
La Meseta	Tolima	3	56	75	29	1600	1977	2003
Manuel M. Mallarino	Valle	4	13	76	19	1331	1969	2010
Heraclio Uribe	Valle	4	17	75	54	1608	1953	1991
Venecia	Valle	4	20	75	50	1168	1985	2010
Sec. De Agricultura	C/marca.	4	21	74	22	1750	1951	1986
Granja Tibacuy	C/marca.	4	22	74	26	1538	1952	2010
La Esperanza Quindio	Quindío	4	22	75	45	1428	1982	2010
Paraguaicito	Quindío	4	24	75	44	1203	1963	2010
Mónaco	Quindío	4	25	75	42	1250	1982	2010
La Miranda	Quindío	4	26	75	51	1193	1982	2010
Quebradanegra	Quindío	4	27	75	40	1500	1982	2010
La Bella	Quindío	4	30	75	40	1449	1951	2010
El Agrado	Quindío	4	31	75	48	1275	1984	2010
Misiones	C/marca.	4	33	74	26	1540	1978	2010
El Sena	Quindío	4	34	75	38	1589	1962	2010
Maracay	Quindío	4	36	75	44	1402	1977	2010
Vivero	Quindío	4	37	75	46	1330	1951	2010
Arturo Gómez	Valle	4	40	75	47	1259	1967	2010
Mesitas De Santa Inés	C/marca.	4	43	74	27	1340	1966	2010
Santiago Gutiérrez	Valle	4	44	76	7	1530	1972	2010
Bellavista	Valle	4	45	76	6	1528	1974	2010
La Catalina	Risaralda	4	45	75	44	1321	1987	2010
Albán	Valle	4	47	76	11	1510	1975	2010
La Playa	Risaralda	4	49	75	45	1290	1982	2010
Combia	Risaralda	4	51	75	47	1173	1981	2010
El Bosque	Risaralda	4	51	75	41	1458	1978	2010
La Trinidad Líbano	Tolima	4	54	75	2	1456	1972	2010
El Jazmín	Risaralda	4	55	75	37	1635	1960	2010
Icalí	C/marca.	4	57	74	25	1328	1976	2010
Naranjal	Caldas	4	58	75	39	1381	1956	2010
Cenicafé	Caldas	5	0	75	36	1310	1942	2010
Java	Caldas	5	1	75	32	1778	1980	2010
La Argentina	Caldas	5	2	75	41	1354	1978	2010
Agronomía	Caldas	5	3	75	30	2088	1956	2010
Granja Luker	Caldas	5	4	75	41	1031	1964	2010
Santágueda	Caldas	5	4	75	40	1026	1964	2010
Buenos Aires	Caldas	5	11	75	31	1730	1981	2010
Planta De Tratamiento	Risaralda	5	17	75	53	1600	1970	2010

Station name	Department	Latitude (N)		Longitude (W)		Altitude	Historical series	
		Degrees	Min	Degrees	Min	m	Start	End
El Diamante	Risaralda	5	19	75	42	1550	1981	2010
Ospirma	Risaralda	5	20	75	49	1661	1981	2010
La Oriental	Risaralda	5	22	75	43	1730	1981	2010
Llanadas	Caldas	5	23	75	33	1800	1956	1998
Montelíbano	C/marca.	5	27	74	20	1365	1960	2010
Rafael Escobar	Caldas	5	27	75	38	1307	1971	2010
El Descanso	Caldas	5	30	75	37	1800	1980	2010
Santa Helena	Caldas	5	35	75	33	1400	1980	2010
Miguel Valencia	Antioquia	5	36	75	51	1621	1953	2010
Guaymaral	Caldas	5	39	75	27	1600	1961	2010
CuatroEsquinas	Caldas	5	40	75	25	1900	1983	2010
La Blanquita	Antioquia	5	49	75	41	570	1984	2010
La Cumbre	Santander	5	52	73	41	1691	1979	2010
Bariloche	Antioquia	5	55	75	42	1748	1980	2010
El Rosario	Antioquia	5	58	75	42	1635	1967	2010
CieloRoto	Santander	6	7	73	22	1504	1977	2010
Villanueva	Santander	6	14	73	10	1450	1965	2010
Las Flores	Santander	6	29	73	11	1700	1977	2010
Santa Rita	Santander	6	35	73	8	1600	1979	2010
Cocal	Santander	7	16	73	9	700	1986	2010
Blonay	N. de S/der.	7	34	72	37	1250	1951	2010
Francisco Romero	N. de S/der.	7	44	72	47	903	1955	2010
Pueblo Bello	Cesar	10	25	73	34	1134	1958	2010
La Victoria	Magdalena	11	8	74	6	1100	1951	2008
Jirocasaca	Magdalena	11	12	74	4	773	1968	1999

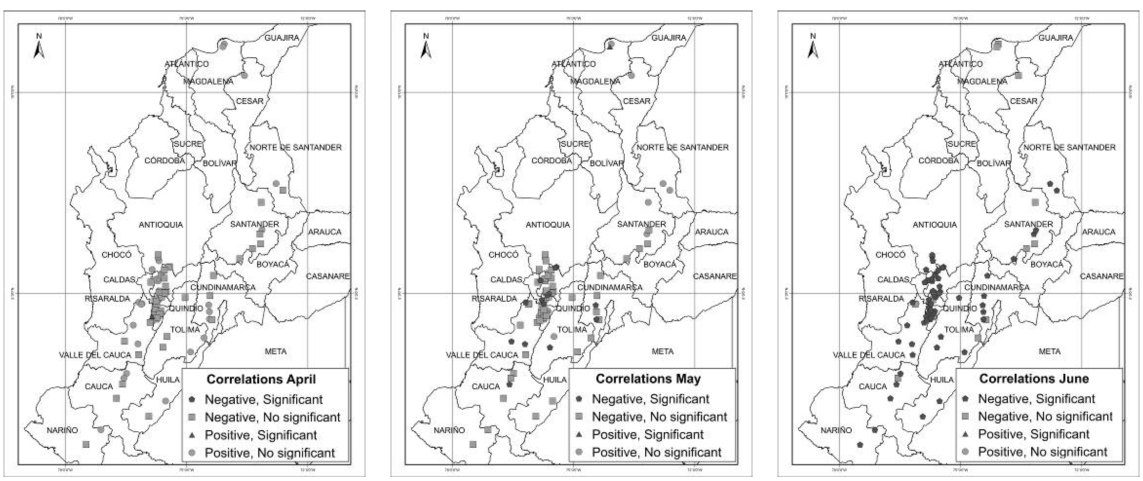

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Fig. 2. Monthly correlation between the ONI and the number of days with rainfall in the weather stations of the Colombian coffee zone, a) April b) May c) June

3.4 October to December

Overall, between October and December the relation between the ONI and the variable under analysis increases. In fact, at some stations in the departments of Antioquia, Caldas, Nariño, Valle and Santander positive values were obtained, although they were not significant in the correlation during October. This shows that in this specific month there is no clear relation between the ONI and the number of days with rain. In November, the relation between the ONI and number of days with rain is not very high but it is significant in most stations. Also during this month there is not a strong distinct relation at the level of regions (north, center and south) between the ONI and the number of days with rain. Between November and December the values of the correlation coefficient is negative in the northern coffee zone. In December, there were no significant relations in less than 10% of the stations analyzed (Fig. 4).

3.5 Discussion

The results show that the effect of the ONI on the number of days with rain is differential and it depends on the area being analyzed. The effect is similar in the central and southern coffee regions, whose behavior is totally different from the coffee zone of the Sierra Nevada de Santa Marta (northern coffee zone). In the north, the ONI has a positive relation with the number of days with rain in the first half of the year, similar to that behavior reported by [26]. This shows that during the first half of the year there is a great uncertainty when the ONI is used to determine the weather to come. However, [26] used the Multivariate ENSO Index (MEI) as an indicator to determine it, which means that the weather of this area of the country is linked to what happens in the Pacific Ocean only during the second half of the year. The use of MEI as an effective index to relate climate variability and crop yields variability, with the changes in the Pacific Ocean, has been widely reported by [30]. It is because it has shown to be more effective in describing ENSO events than other indices in some regions,

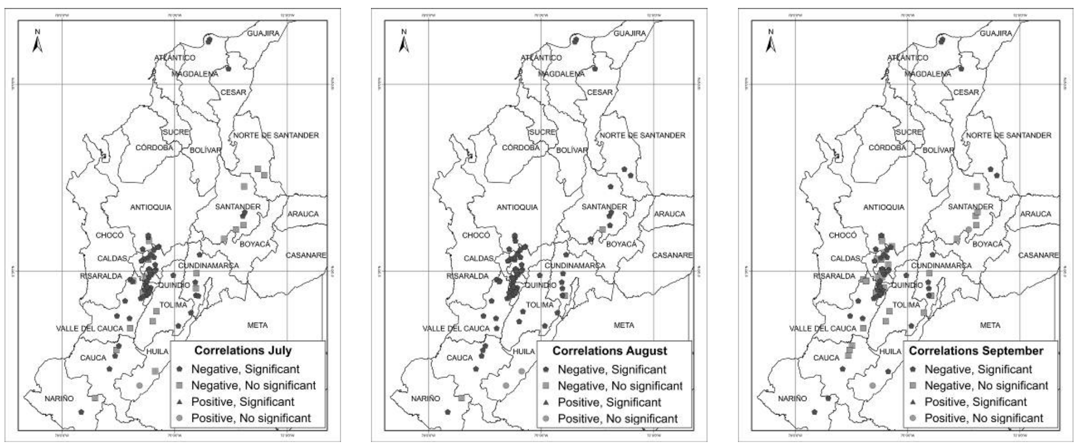

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Fig. 3. Monthly correlation between the ONI and the number of days with rainfall in the weather stations of the Colombian coffee zone, a) July, b) August, c) September

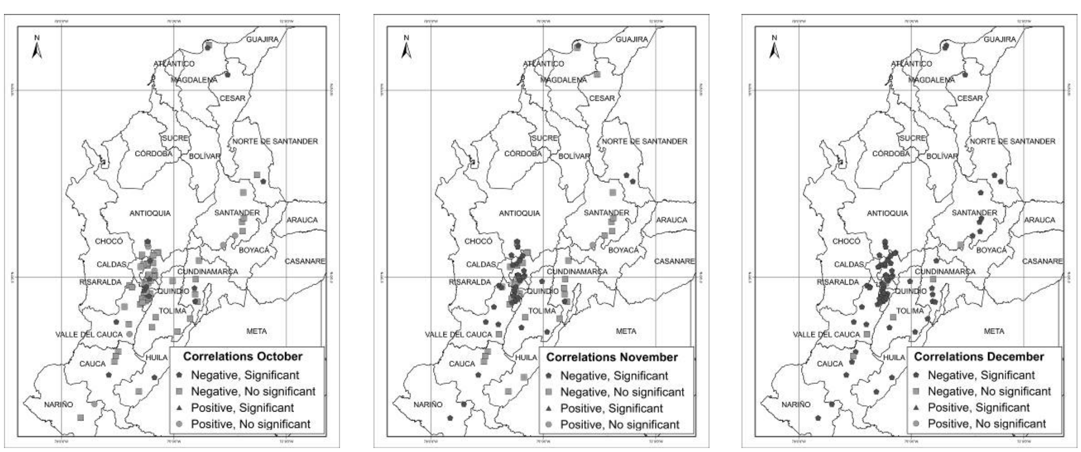

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Fig. 4. Monthly correlation between ONI and the number of days with rainfall in weather stations Colombian coffee zone, a) October, b) November c) December

such as ONI, SST, SOI, etc. [31]. However, among decision makers MEI has not been as widespread as ONI.

The central coffee and south coffee areas have a great ONI effect during the historically dry months; this behavior was described by [22] in the sugar region of Colombia and by [17] in the central coffee zone (Caldas, Tolima, Antioquia and Valle del Cauca). Results reported in this work will be used as an input when coffee growers are going to make decisions like was reported by [32]. According with this author, the effect of El Niño/La Niña on the rainfall in the US depends on the region. That work shows that the effect of ENSO on the cotton production in the southeastern United States is greater when the phenomenon (El Niño/La Niña) coincide with the planting season. It is because the amount of the rain during the growth stage of the plants is greater under El Niño conditions than under La Niña [32,33].

In spite of, an important effect of the ENSO can be described by ONI, and its effect on climate and crop production is marked during the dry seasons; this index cannot be used widely through the year. Because the anthesis, it is important that it describes the intensity of the wetness in dry seasons. However, the coffee berries grow up on wet seasons, when ONI does not show a relationship with the rainfall. It means that ONI can be used in order to qualify the anthesis, mainly in the stations located in the central area (3º and 7º North) of Colombia, where highest correlations between rainfall (represented as the number of days with the rain) and the Oceanic Niño Index were; specifically for dry months (January, February, March, June, July, August, September and December). That is to say that the index cannot be used to predict the production because the fruit filling depends not only on the anthesis, which is determined by the effect of a dry season. It depends on the length of the wet season too, and it is because coffee crops in Colombia do not have irrigation. In this case, it would be important to know the relationship between rainfall and ENSO in rainy seasons like was reported by [34].

4. CONCLUSION

As part of the analysis of this study it can be concluded that the stations located in the central area (3º and 7º North) of the country have the highest correlations of the variable rainfall, represented as number of days with rain with the Oceanic Niño Index for the months of January, February, March, June, July, August, September and December. For the months of April-May and October-November the correlations are lower, even some stations at this time of year show positive correlations between the index and the variable, this as a result of the passage of the ITCZ.

There are stations such as La Trinidad (Cauca) and La Catalina (Risaralda), where the ONI could be used as a tool to proactively determine in advance the effect of rain on coffee cultivation since the correlation between the index that characterizes the Pacific and the number of days with rainfall is significant during all months of the year. In the rest of the meteorological stations analyzed, there are months when the ONI effect on the weather variable does not show more than uncertainty (correlation coefficients close to zero).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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