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Agrometeorology and climate change

Tropical rainfall conditions in rainfed agriculture in Carabobo, Venezuela

Condiciones tropicales de la lluvia estacional en la agricultura de secano de Carabobo, Venezuela

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Abstract

Variability and climate change are having a strong impact on different meteorological variables; inducing changes in the precipitation pattern that directly affects water availability in agroecosystems. It is for this reason that the objective of this work was to analyze the interannual variability of tropical rainfall and its influence on rainfed agriculture of the Lake of Valencia basin in Venezuela. For this, the monthly and annual precipitation data (1969-1999) of eight climatological stations were used. Subsequently, the basic descriptive statistics were calculated, the evolution of the precipitation was described and finally, it was calculated from the P90% -10% percentile range as an indicator of the variation of the series amplitude. The results establish that there are changes in the interannual precipitation regime and, after analyzing trends in annual precipitation in Yuma Caserio, Colonia El Trompillo, Agua Blanca and Las Dos Bocas, there is a generalized reduction in rainfall, would negatively affect the generation and availability of moisture in agricultural locations, which depend heavily on rainwater. The agricultural vocation in the lowlands of the lake basin of Valencia makes it very vulnerable to persistent dry episodes, where rainfed crops such as industrial sorghum, maize, vegetables, fruits (musáceas) and citrus fruits diminish their yield during the absence prolonged rainfall, affecting the agricultural sector of the region.
Keywords: Seasonality, precipitation, tendency, agrometeorology.

Resumen

La variabilidad y el cambio climático están teniendo fuertes repercusiones sobre diferentes variables meteorológicas; induciendo cambios en el patrón de precipitación que afecta directamente la disponibilidad hídrica en los agroecosistemas. Es por esta razón que el objetivo de este trabajo fue analizar la variabilidad interanual de la lluvia tropical y su influencia en la agricultura de secano de la cuenca del Lago de Valencia en Venezuela. Para esto se utilizaron los datos mensuales y anuales de precipitación (1969-1999) de ocho estaciones climatológicas. Posteriormente, se calcularon los estadísticos descriptivos básicos, se describió la evolución de la precipitación y por último, se calculó del rango percentil P90%-P10% como indicador de la variación de la amplitud de la serie. Los resultados establecen que existen cambios en el régimen interanual de la precipitación y, tras analizar las tendencias en la precipitación anual en las localidades Yuma Caserío, Colonia El Trompillo, Agua Blanca y Las Dos Bocas, existe reducción generalizada en la lluvia, estos cambios, afectarían negativamente la generación y la disponibilidad de humedad en las localidades agrícolas, las cuales dependen fuertemente del agua de lluvia. La vocación agrícola en las tierras bajas de la cuenca del lago de Valencia, la hace muy vulnerable a los episodios secos persistentes, donde los cultivos de secano como sorgo industrial, maíz, hortalizas, frutas (musáceas) y cítricos merman sus rendimientos durante la ausencia prolongada de lluvias, lo que afecta al sector agrícola de la región.

Palabras claves: Estacionalidad, precipitación, tendencia, agrometeorología.

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1 Introduction

For the subsistence of the agricultural sector, which faces growing climate risks, timely and accurate information on weather, climate and water is essential. Observations, predictions and analyzes made in research allow agricultural communities to increase livestock production and crop yields, plan sowing and harvesting seasons, and reduce pests or diseases (OMM, 2009; Olivares, 2009).

The rainfed tropical agriculture developed in the country, and specifically that of the Carabobo state, is considered a risky business, mainly due to the influence of intra-annual and inter-annual variability in the availability of crop water and the possibility of carrying out mechanized agricultural work.

The tropical characteristics of the sub-humid zones under study, are represented by the precipitation higher than the evapotranspiration in part of the year and lower in other months (seasonal deficit more common and severe, precipitation regime can be very erratic); whose dominant environment is characterized by presenting high to moderate fertility soils, where a large part of the production of vegetables, corn and sugarcane is found in the central region. Class (I) lands predominate, with well-drained deep soils that are easy to work, without any or slight restrictions on their use (Comerma y Parede, 1978; Zinck, 2012).

According to the investigations developed by Martelo (2003); Guenni *et al*. (2008); Guevara *et al*. (2008); Lobo *et al*. (2010); Cortez *et al*. (2011); Olivares *et al*. (2012, 2013a); Paredes *et al*. (2015), it is established that in mid-April the displacement north of the Atlantic anticyclone, allows the advance of the Intertropical Convergence Zone (ITCZ), establishing itself over a large part of the country. The ITCZ allows us to signal the beginning of the rainy season in Venezuela, which lasts until the beginning of November. With the progressive withdrawal of the ITCZ to the south; outside the Venezuelan territory, and the increase of the influence of the Atlantic anticyclone on the country, the beginning of the dry season is established, which extends until the month of April.

Rain is considered as a space-time process within the climate system, since it exhibits random aspects both in time and space and whose structure of variability can be explored by appropriate statistical techniques (Pradere, 1999; Toledo y Hernández-Szczurek, 2003). One of the aspects to be considered in meteorological studies is represented by the evolution of precipitation and the possible impact that climatic variability has on it, that is why the variability of seasonal tropical rain is important as a descriptive parameter of the series of observation and more when it has implications for rainfed agriculture.

The objective of this research is to study and define the main characteristics of tropical rain events of seasonal importance in rainfed agriculture, developed in the Lake of Valencia basin, Carabobo state, Venezuela. In this sense, the initiative to develop research on the likely evolution of climate, the variability of climatic elements and the influence on socio-economic activities, contribute to improve agricultural production and sustainability and, at the same time, the food security of the nation.

2 Materials and methods

2.1 Study area

In the study area, the predominant natural region is the depression of the Lake of Valencia, comprising the Serranía del Litoral, the Interior and the Depression of Valencia, which constitutes types of landscapes of mountains and valleys, with an area of 2 300 km^2 (MARN, 2005). The valleys bordering the lake and the rest of geomorphological landscapes such as plains, hills and mountains are the product of the interaction of a group of rivers and the tectonics of the region (La Victoria fault in the west-east direction) (Figure 1). The slopes are steep in mountainous areas reaching 70% and in the depression, the slope ranges between 1 and 5% (INE, 2011).

The study area has a dry sub-humid climate with annual rainfall ranging between 921 mm and 1 063 mm. The rainfall regime describes a Unimodal type distribution with two defined periods; a rainy season between May to October, and a dry season between November and April. the altitude conditions of the Depression of the Lake of Valencia (400-500 msnm) and its location between two mountainous areas, generate not so fresh conditions considering the altothermic gradient, rather they remain with a slow gradual decrease, and in general a little warm, registering in Valencia (478 masl), an average annual temperature of 24.6°C (Hernández *et al*., 2017).

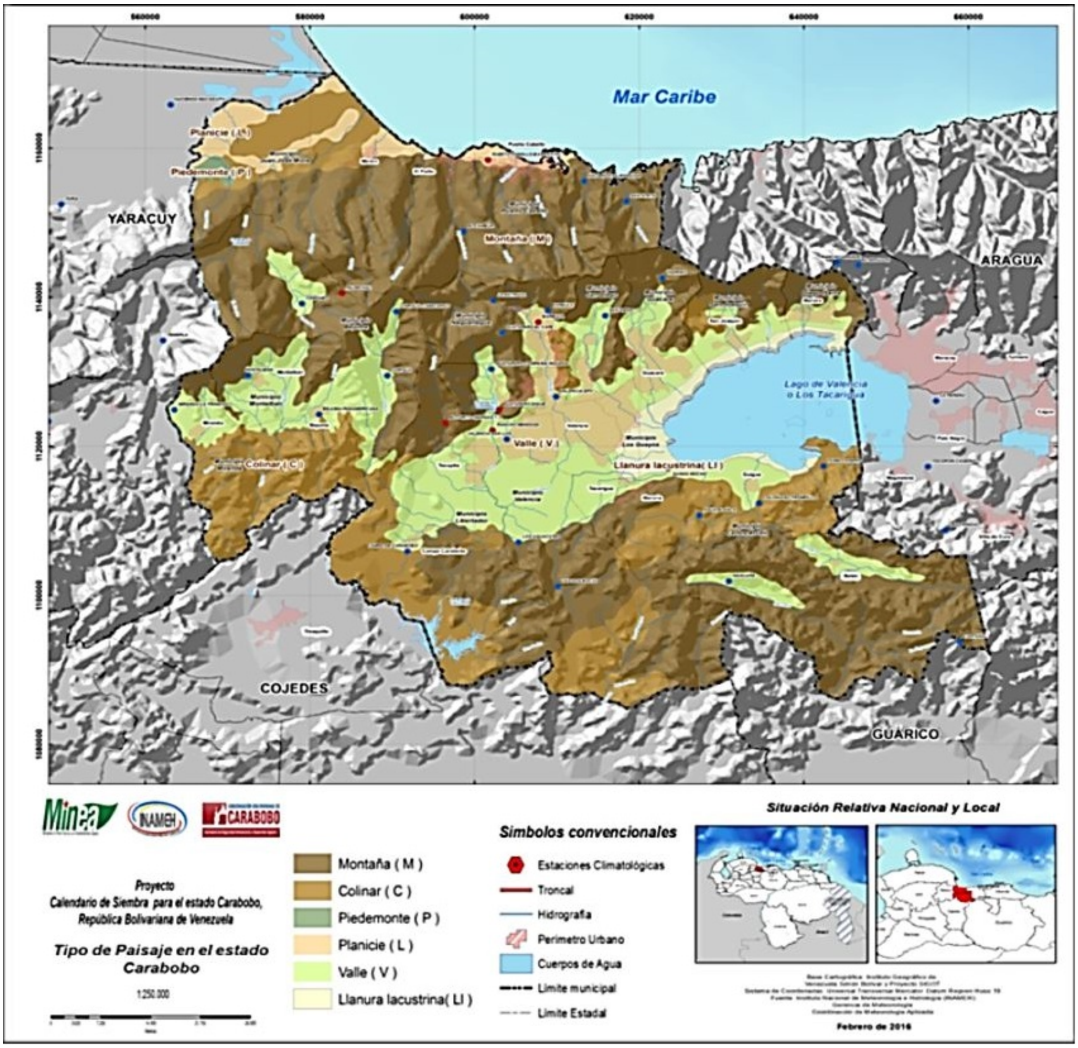


Figura 1. Type of Landscape in the state of Carabobo, Venezuela (Hernández *et al*., 2017).

2.2 Precipitation data

For this study, the monthly rainfall data (1969-1999) from eight meteorological stations, located in the Lake of Valencia basin, Carabobo state (Table 1), were obtained from the data bank of the Processing Management and Data quality of the National Institute of Meteorology and Hydrology of Venezuela.

The selection of this period of time (1969-1999) was based on the accuracy of the series, which consisted in the correctness of the data, as well as the validity referred to the applicability of the data in order to establish the trends of the temporal series data. The decision not to consider the current period of precipitation data was associated with the fact that more than 33 % of the total weather stations had uninterrupted and extensive periods of missing data within the historical record, in addition there was a significant portion of stations that were dismantled in During 2001-2010, they did not have rain data as of the year 2000.

Tabla 1. Geographical description of rainfall stations located in the Lake of Valencia basin, Carabobo state, Venezuela.

Stations	Municipality	Landscape	North	East	Altitude (m.s.n.m)
Vigirima	Guacara	Mountain	1 142 558	622 845	557
San Diego	San Diego	Valley	1 137 558	615 956	460
Valencia-GFV	Valencia	Valley	1 126 726	609 967	460
Yuma-Caserio	Carlos Arvelo	Hill	1 117 317	642 415	460
Colonia El Trompillo	Carlos Arvelo	hill	1 112 434	634 579	450
Agua Blanca	Carlos Arvelo	Hill	1 110 749	627 339	515
Las Dos Bocas	Valencia	Mountain	1 101 292	610 166	550
Bárbula	Naguanagua	Mountain	1 136 672	607 806	493

Quality control was carried out on the monthly rainfall data to define the proportion of missing data, identify out-of-normal values and observe the basic understanding of the distribution of the series(Parra y Cortez, 2005; Olivares *et al*., 2013b; Guevara, 2003); using the programs JMP v.6 (Jones y Sall, 2011), InfoStat v.11 (Di Rienzo *et al*., 2011) and Vesper v.1.6 (Minasny *et al*., 2002).

2.3 Analysis of time series

The proposed methodology is inserted within the statistical procedures of the analysis of time series, which comprises three phases of study: the first related to the calculation of basic descriptive statistics (mean, median, variance, standard deviation, coefficient of variation, kurtosis , asymmetry, maximum and minimum values, the 1st and 3rd quartiles); the second phase was to describe the secular evolution of precipitation (1969-1999), which consisted in the typing of the annual values of precipitation and from these, execute both the calculation of moving averages centered in two years, and that of the trend line calculated with the minimum number of squares; finally, the calculation of the percentile rank P90 % -P10 % as an indicator of the variation of the amplitude of the series.

3 Results and discussion

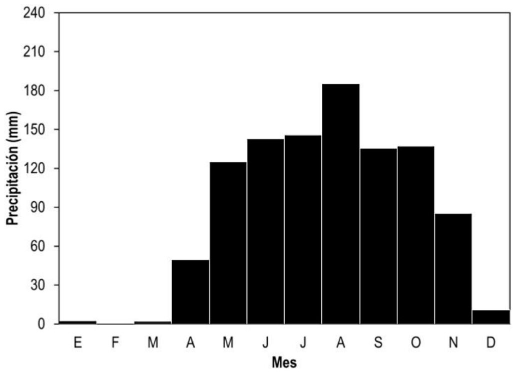
3.1 Behavior of medium precipitation (1969-1999)

Figure 2 shows the behavior of the median precipitation for the stations under study. Throughout the Lake Valencia basin, the amount of precipitation is extremely variable both in time and space. During the months of the dry season (January to March) all the localities present average rainfall less than 40 mm, with a high proportion of zero values.

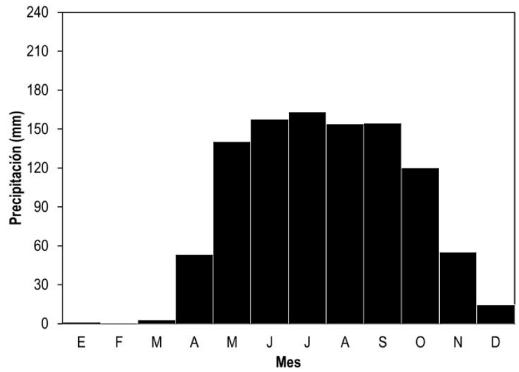
During the months of April and May the values of medium precipitation increase, with a rise from northwest to southeast, which indicates the advance of the Intertropical Convergence Zone (ITCZ), keeping values in the range (50-150 mm) for the most of the locations, except in Agua Blanca (Figure 2g) and Las Dos Bocas (Figure 2h) where the median exceeds this range.

On the other hand, for the months of June, July and August the rainy season in the study region is already established, with median values exceeding 150 mm in most seasons. The locality of Yuma Caserío (Figure 2e) presents values lower than 150 mm, being the locality with lower values in the rainy season. The locality Las Dos Bocas presents medium-sized amounts in the range (180-240) because it is located in a slightly humid climate according to Hernández *et al*. (2017).

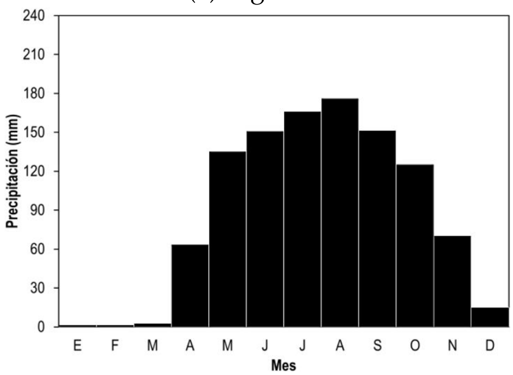
With respect to the months September and October, these present values of median inferior to 150 mm, developing the pattern that began to manifest itself in August, towards the south of the state the precipitation increases significantly during these months. In November and December, a pattern of decreasing rainfall is present throughout the study area.



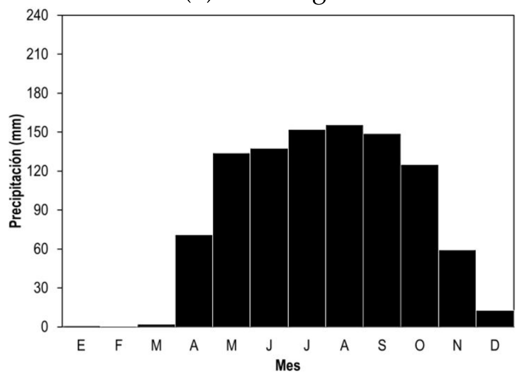
(a) Vigirima



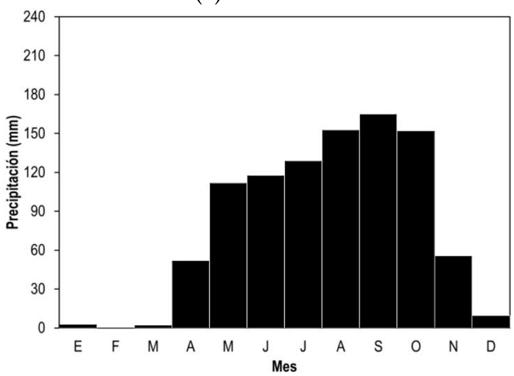
(b) San Diego



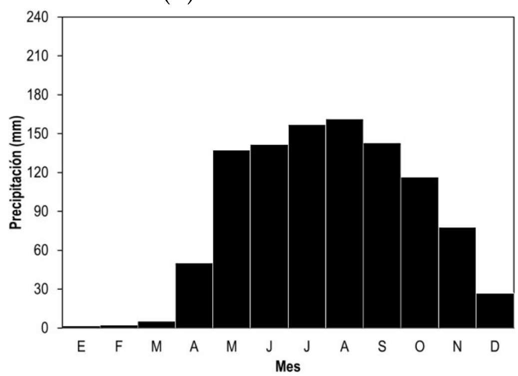
(c) Bárbula



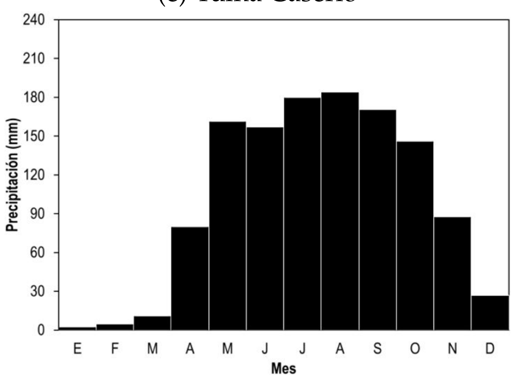
(d) Valencia GFV



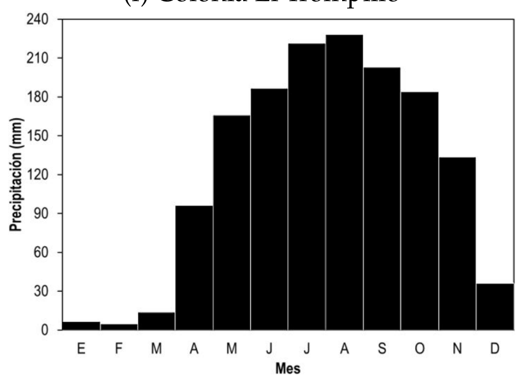
(e) Yuma Caserío



(f) Colonia El Trompillo



(a) Agua Blanca



(b) Las Dos Bocas

Figura 2. Average precipitation (mm) for the period (1969-1999) in the stations under study: (a) Vigirima; (b) San Diego; (c) Bárbula; (d) Valencia GFV; (e) Yuma Caserío; (f) Colonia El Trompillo; (g) White Water; (h) The Dos Bocas.

3.2 Behavior of statistic descriptors

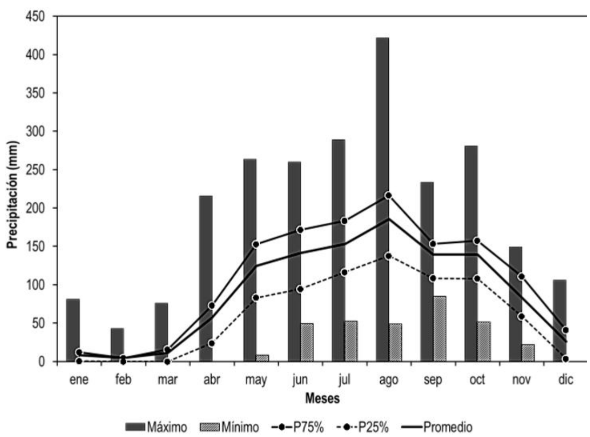
The graphical representations of each locality (Figure 3) showed acceptable and logical values within the ranges reported by the First National Communication of Climate Change in Venezuela (MARN, 2005). A characteristic of this region is the marked seasonality of precipitation, due to the alternating action of the intertropical convergence zone. The rainy period concentrates more than 85% of the total annual precipitation, while in the dry months it rains very little, being the monthly precipitation lower than the reference evapotranspiration; It is very frequent that in the months of February and March the rainfall registered is zero millimeters (Martelo, 2003).

The statistical results that describe the seasonality of the rain in the area under study coincide with the climatic characteristics of the region (Guenni *et al.*, 2008; Olivares *et al.*, 2013b, 2017). The annual variability of precipitation in Venezuela is highly influenced by the prevailing geographical conditions such as the presence of the La Costa mountain range and its interaction with the Caribbean Sea; as well as the migration of the Intertropical Convergence Zone that originates the unimodal regime in the area.

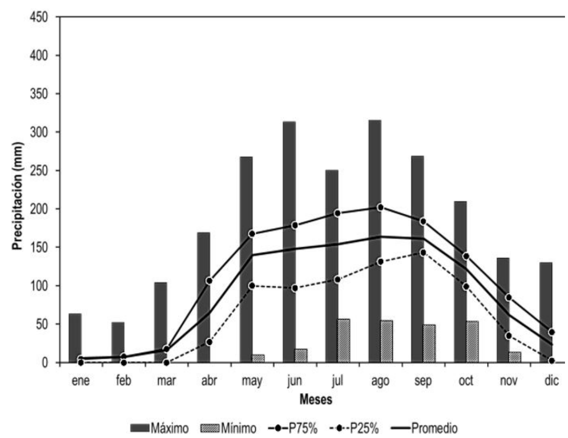
The generalized dry events of a relevant nature occur mainly in the months of the rainy season and in the months of November and December, bringing negative consequences for the growth and development of crops. There is a significant difference with respect to the dry events that are concentrated in the months of April to August; it seems that rainy events can occur at any time due to the origin of the precipitation in the area. In this regard, Martelo (2003) points out that the rainy events recorded in the historical series between the months of January and February can be very likely the consequence of the arrival of Cold Fronts, while dry events in the rainy season may be due to a higher-than-normal East Waves passage or a particularly intense hurricane season.

A typical characteristic of tropical rain is the occurrence of great intensity; as indicated by González y Córdova (1992) with durations between 30 minutes and 6 hours; in turn, the study developed by Goldbrunner (1984) states that 95% of rainfall falls in the form of rain showers of 15 to 30 minutes, often in the afternoon.

The study area is notable for its agricultural and livestock production especially in the western valleys and on the banks of Lake Valencia. It is the main producer of items such as corn, tobacco, cotton, coffee, cocoa, sugar cane, banana, yam, potatoes and citrus. In this order of ideas, one of the main problems faced by rainfed agriculture is the great variability that spatial rain presents and temporarily, which affects the variability of the beginning, end and length of the growing season, which are important parameters within the agricultural activity.



(a)



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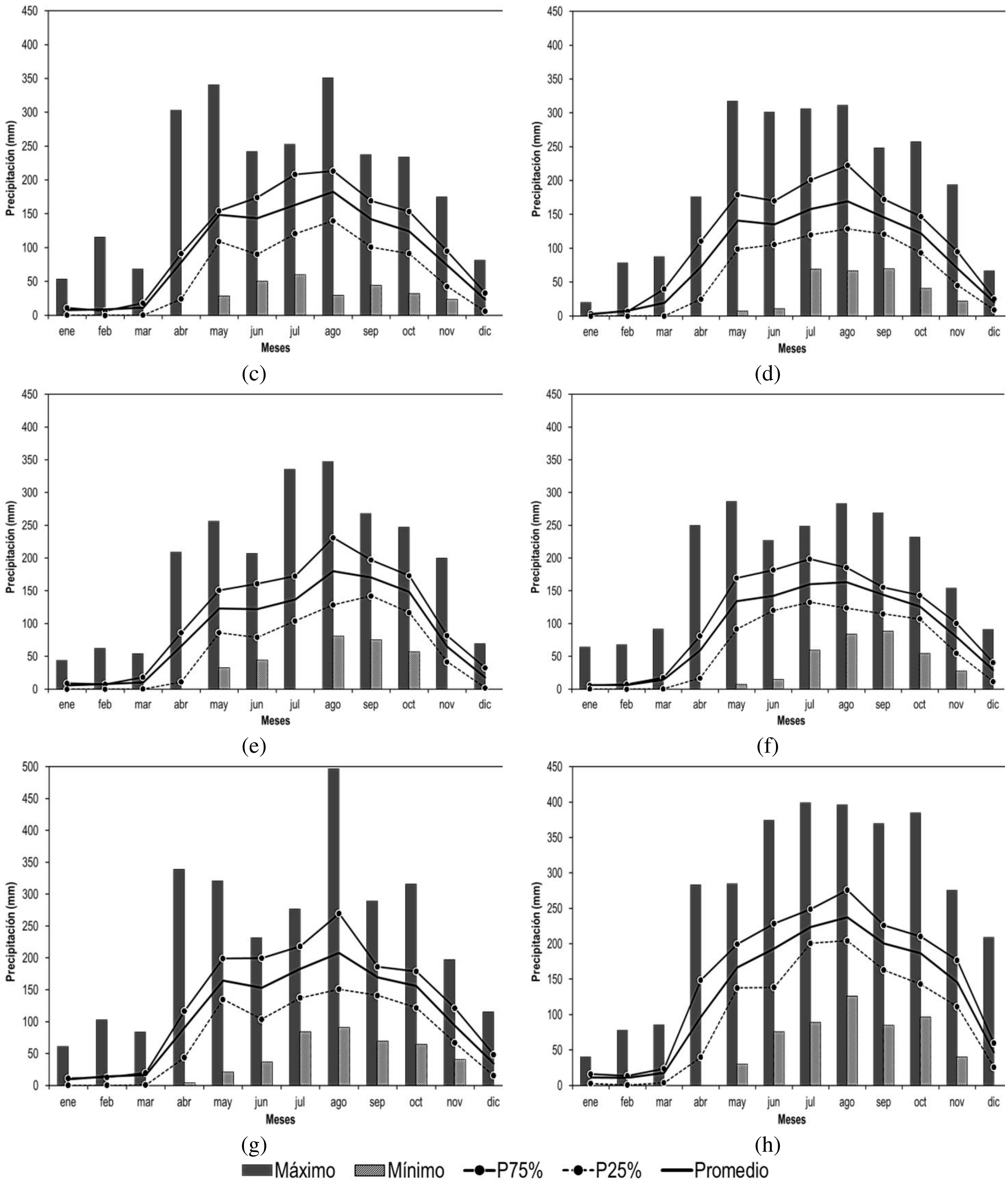


Figura 3. Behavior of average monthly precipitation (mm), maximum, minimum, 75 % and 25 % percentiles for the stations under study: (a) Vigirima; (b) San Diego; (c) Barbula; (d) Valencia GFV; (e) Yuma Caserio; (f) Colonia El Trompillo; (g) White Water; (h) The Dos Bocas..

In these localities where the variability of rainfall is high, it is not recommended to use the average value, particularly because they are located in a subhumid region, areas where rainfall is usually used and where the variability of precipitation tends to be high. It is more appropriate to use a value whose probability of occurrence is greater than 50 % (for example, 75 % or more), depending on the local characteristics of the precipitation, the type of use and the scarcity situation. Generally, the more severe the situation of scarcity and the priority is the type of use, the less uncertain the amount of water available must be.

The management of information on the water deficit can guide and even modify the sowing dates of the crops in order to have a lower water deficit. Although it may seem obvious, this type of study allows the producer or planner to be guided when selecting the sowing dates, seeking to coincide the periods of least probability of deficit (higher values of the design rain) with the most critical period of susceptibility of the crops, usually the reproductive. The aim is to find an adjustment between the water demand of the crops and the availability of water in the period.

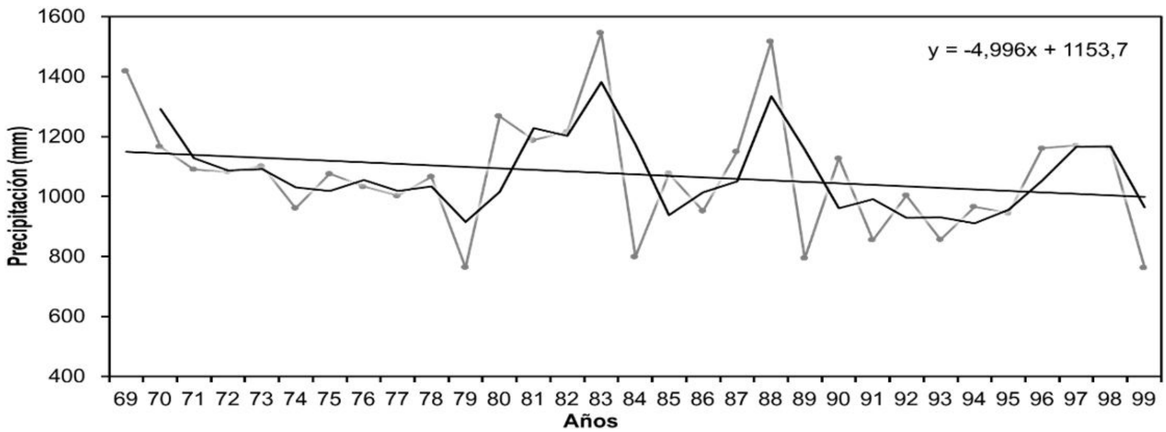
In particular, the length of the cycle of crops growing in the study area (cereals, vegetables and tubers) should be shorter than the length of the most likely growing season (less than five months).

The lack of significant water, in a rainy month and under rainfed agricultural conditions, puts the agricultural producers of the area in a hurry, who, faced with a reality that is repeated year after year, must elaborate a series of strategies to manage with success this situation. Considering the magnitude of the water deficit in these agricultural areas of the state of Carabobo, drought episodes should be addressed through a greater allocation of resources for the construction of deep wells, also taking advantage of the rivers and nearby streams.

On the contrary, the excesses of water also exert a considerable influence on the logistics of the agricultural harvest, so, for those areas of ample size and whose technological package allows it, the machinery must be in operating conditions so as not to waste time of harvest days for foreseeable breaks. In addition, it is likely that the network of roads or agricultural roads is in a situation of impassable, so it should be organized with time storage in the field and its subsequent care according to storage moisture and storage conditions.

3.3 Evolution of annual precipitation (1969-1999)

The curves of the moving averages (Figure 4), recorded the lowest values in the years 1979 (generalized drought), 1985 and 1990 for the localities San Diego (Figure 4b) and Bárbula (Figure 4c), coinciding with the minimum values of Vigirima (Figure 4a), except for the 1994 period. For its part in Valencia (Figure 4d), the lowest moving average was presented during the years 1997 and 1990.



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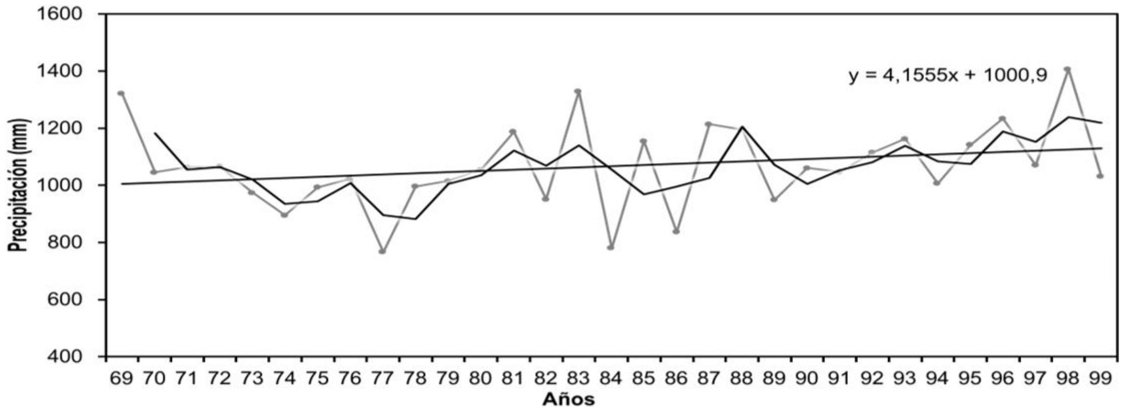

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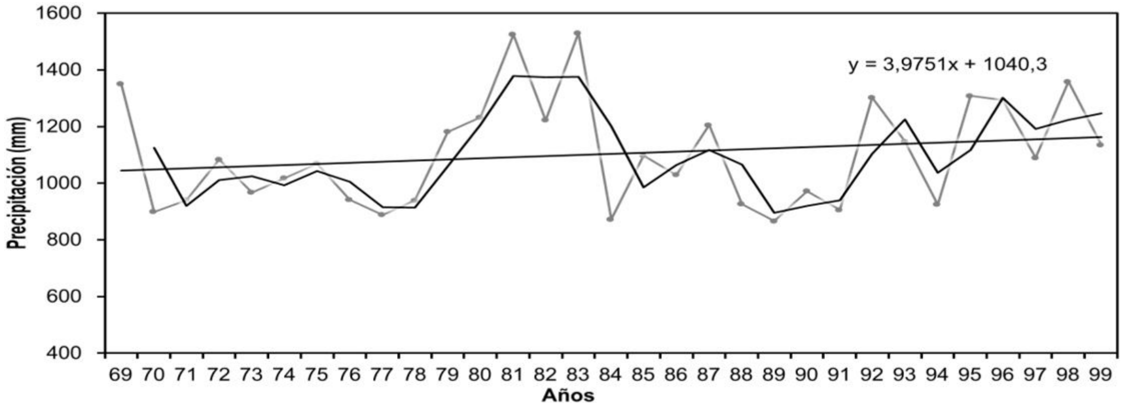

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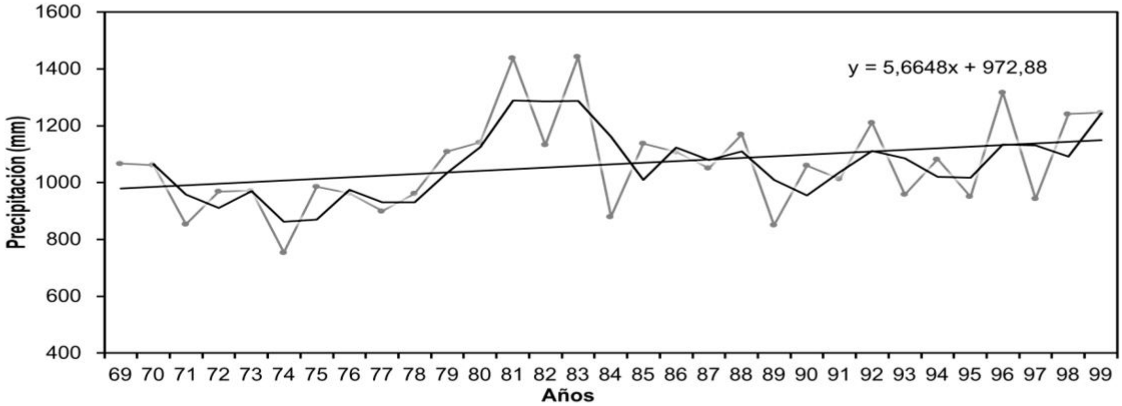


(d)

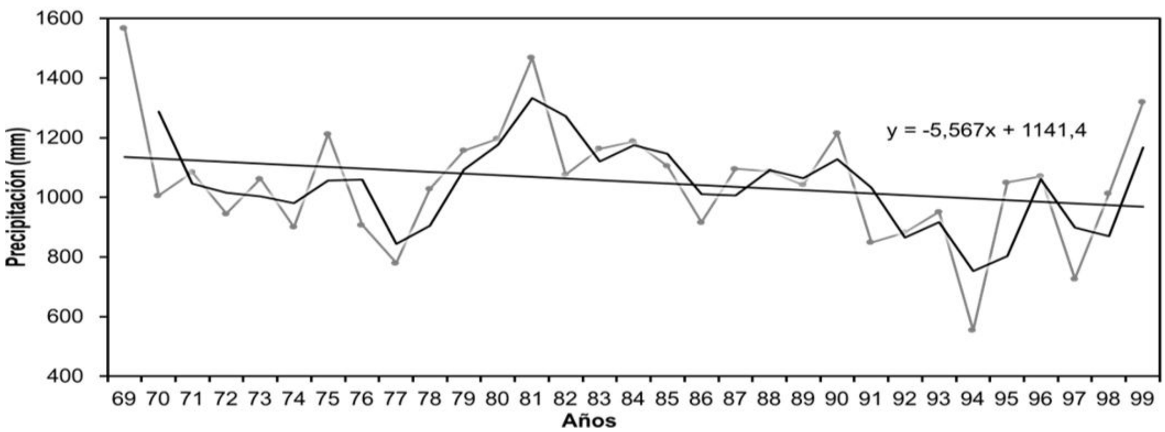
Figura 4. Evolution of annual rainfall (1969-1999) for the stations under study: (a) Vigirima; (b) San Diego; (c) Bárbula; (d) Valencia GFV.

From this graph it can be seen that the southeastern part of the Carabobo state has a negative tendency in precipitation, represented by the localities Yuma Caserío (Figure 5a), Colonia El Trompillo (Figure 5b), whose lowest values of moving average are recorded during the 1977 and 1994; On the other hand, in Agua Blanca (Figure 5c) the driest years were 1974 and 1997, while in Las Dos Bocas (Figure

5d) the dry years were 1980 and 1989.

For most of the localities analyzed, the trend component is not statistically significant, however, the values obtained from negative slopes for the study area are in agreement, at least in sign, with the reports of Guenni *et al*. (2008). The negative slopes can also be evidence of a greater activity of the phenomenon ENSO (El Niño-Southern Oscilation) in recent years, given the negative impact of the warm phase of ENSO (El Niño) on the precipitation of the northern region of South America (Poveda *et al*., 2006).

The analysis of these negative trends could raise the possibility of a reduction in the number of wet months, which limits the use of both annual and perennial crops, depending on the magnitude of the reduction. The distribution of precipitation will be affected, an example of this is the analysis of the distribution derived from the study of Martelo (2003), where the highest incidence is in the month of May, which corresponds to the preparation of the land and planting of the main crops in most agricultural areas; with incidences also in the month of August, month that corresponds with the flowering, fructification and filling of grains mainly of cereals.



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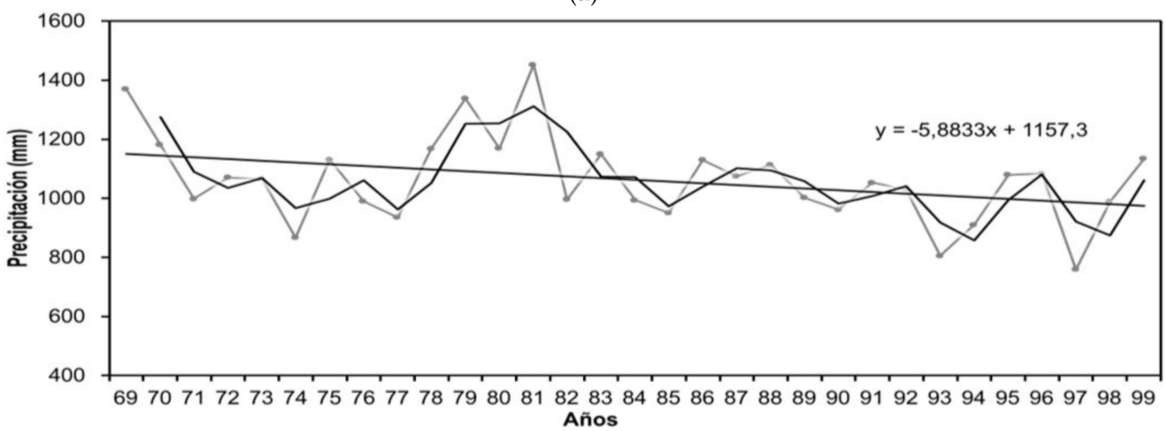

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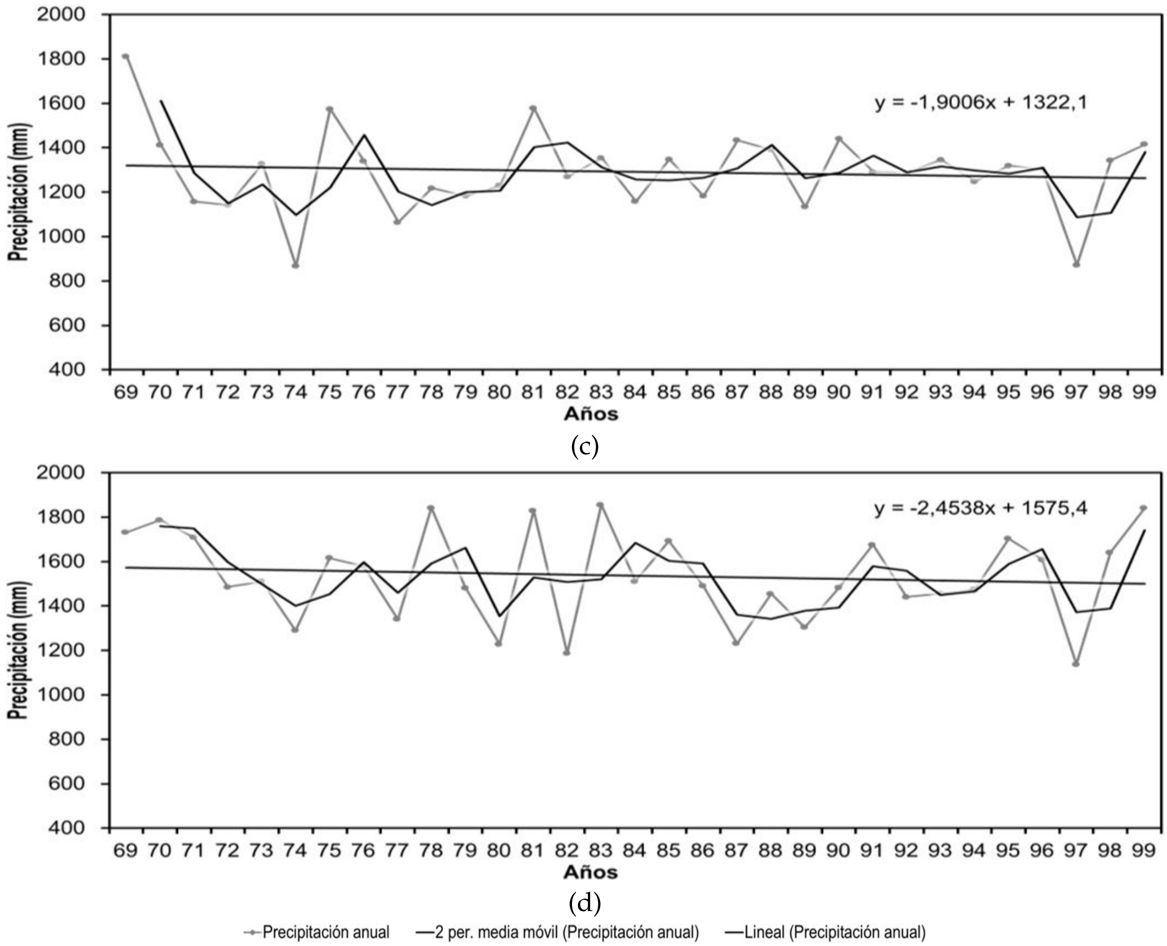


Figura 5. Evolution of annual rainfall (1969-1999) for the stations under study: (a) Yuma Caserío; (b) Colonia El Trompillo; (c) White Water; (d) Las Dos Bocas.

This pattern coincides with the threats associated with Climate Change, given that global studies have estimated, among others, alterations in the climate system and changes in the seasonality of precipitation with an increase in the intensity of dry periods with strong repercussions on the hydrological cycle (MARN, 2005; Ovalles *et al*., 2008).

According to the above, the Carabobo state has a harvested area of 6,970 hectares where 65% corresponds to sugar cane, 16% to cereals, the remaining 19% distributed among cocoa, banana, banana, tobacco, paprika and tomato. Already in these areas most of the items mentioned (cocoa, sugarcane, vegetables, musaceas and cereal seed) are at least partially under irrigation. This will create greater competition for water with other uses such as urban water and will require much more efficient irrigation methods than current ones to stay in the area.

Given the estimated impact of the average reduction in the annual water supply in the towns of Yuma Caserío, Colonia El Trompillo, Agua Blanca and Las Dos Bocas, it should be understood that it is necessary to understand the possible repercussions due to changes in the concentration of precipitation in a daily and hourly scale, which in turn will help to determine in a more precise way the future adaptations in the agro-productive systems of Carabobo to face the risks by changes in the frequency and intensity of rainfall events.

That is why the impacts of climatic trends determine the relevance of undertaking coordinated actions on the agricultural territory, given that the changes in the upper parts of the sub-basins that comprise it, will also affect the activities in the middle and lower zones, as well as in the population and the different agro-productive sectors.

The results induce a possible increase in the monthly precipitation at lower altitude, on the representative Valley in the localities San Diego and Valencia, this will imply technological adaptations of some units of agricultural production, mainly for agriculture that is actively developed in this area of the basin of the Lake of Valencia, referred for example to modifications on the dates of sowing and the programming of the irrigation. However, the greater estimated impacts of reduction in annual precipitation towards the southern zone, can have a strong impact on a decrease in the water supply and the consequences on less water to satisfy the water needs of the crops.

3.4 Analysis of the percentile rank P90 % -P10 %

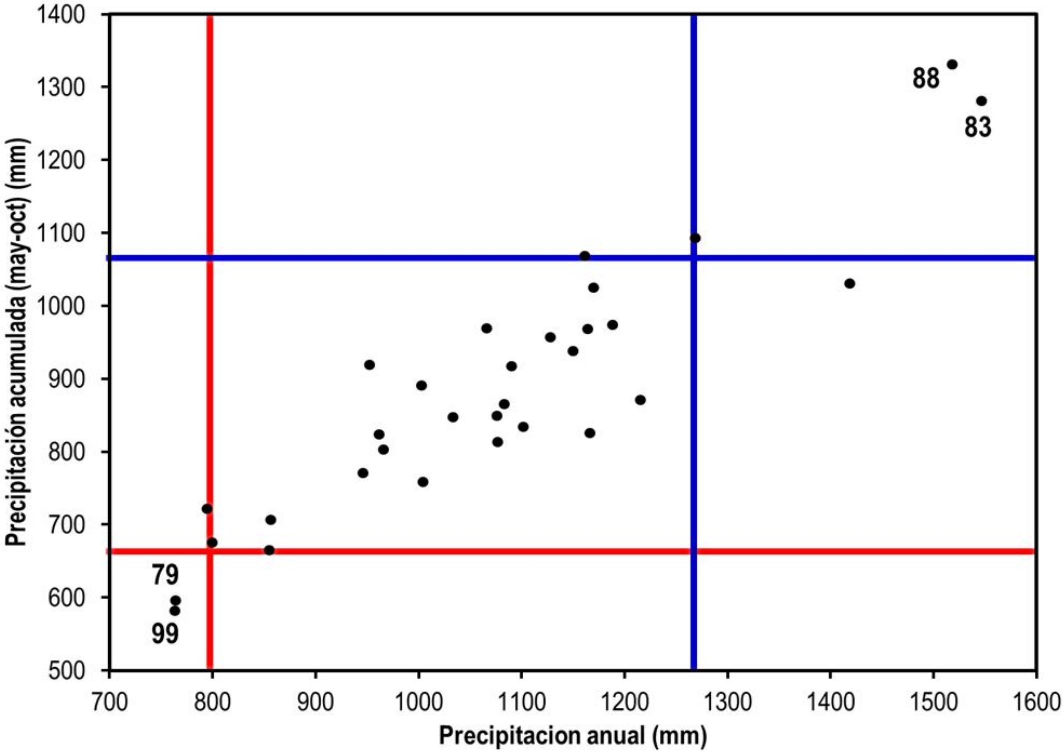
This indicator provides information on the amplitude of the variation in the series, where 87 % of the values of the series present minor differences to this range, and only 13 % of the total values of all the localities under study are considered as values extremes. This information would allow, in a very broad sense, to identify those years where the annual rainfall received compared to the rainfall of the rainy season (May to October) does not manage to be significant or sufficient to cover the water demands of the crops, in the case of dry extremes or, on the contrary, that excess water conditions are generated in humid extreme years, which makes the management of the agroecosystem very vulnerable.

By plotting the annual and seasonal rainfall amounts (May to October), together with the location of the particular years in relation to the percentiles obtained from the historical data series, the wet and dry extremes for two representative localities are defined in the study area. On the one hand, Vigirima (Figure 6a) identifies the years 1983 and 1988 as wet extremes, that is, these years present annual and seasonal amounts above the 90th percentile. The occurrence of these events can determine the failure of the harvest, the drastic reduction of the yields, the affectation of the plantation by favorable conditions for the attack of plagues and appearance of diseases, as well as the increase of the climatic risk that can affect the stability of agriculture in the area. On the other hand, the years 1979 and 1999 correspond to the extreme dry values (<800 mm), being located below the 10th percentile of the annual and seasonal rainfall.

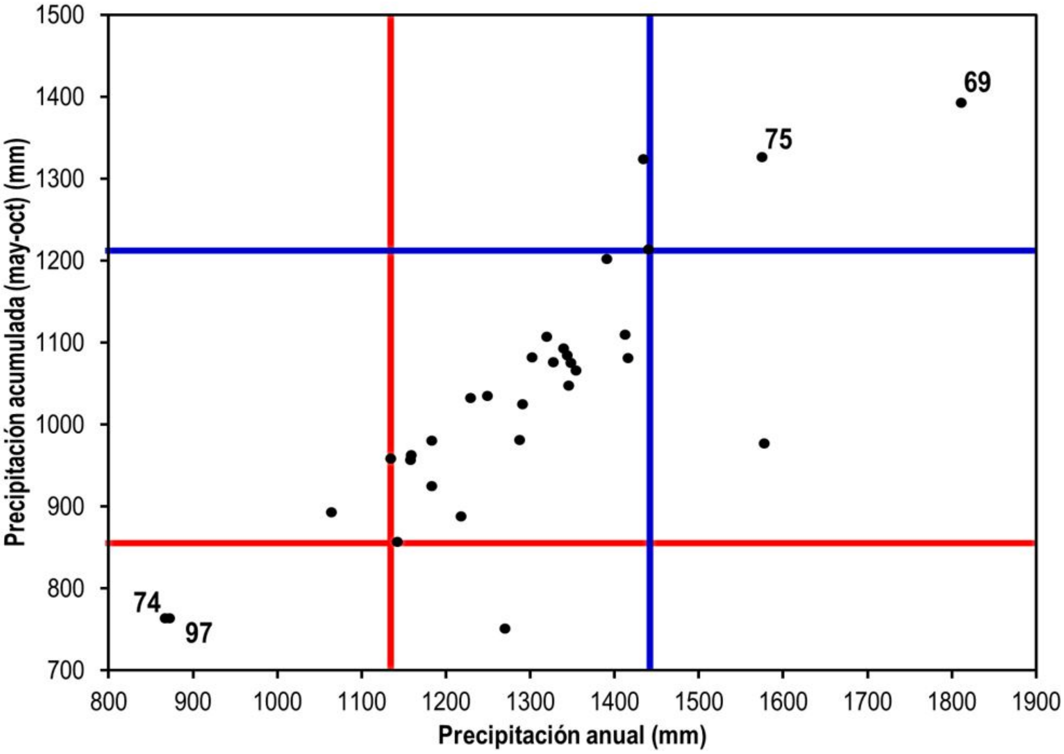
For the period analyzed, the results described show that the phenomenon ENSO (El Niño-Austral Oscillation) can partially explain the occurrence of extremely dry months or humid extremes at local scale during the wet and dry seasons in the lake basin of Valencia (Paredes *et al*., 2015; Olivares *et al*., 2016).

According to Cárdenas *et al*. (2002), El Niño has a greater incidence on rainfall extremes than La Niña at a local scale and is usually related to anomalously dry conditions with moderate spatial coverage. The moderate to scarce connection between the active phases of ENSO identified at the local level suggests that other factors not evaluated had a decisive influence on certain extreme rainfall events (for example, the generalized drought of 1979 occurred during the neutral phase of ENSO).

The strategies of water management in the localities under study would be oriented to maintain high infiltration in the soil; the prevention and control of runoff, given the high risk of water erosion in the humid period for mountainous areas, in addition to promoting techniques to capture and store water in the wet period for use in the dry period (Ovalles *et al*., 2008). Likewise, it is clear that the use of water improvement techniques in the soil, the use of runoff or the use of irrigation (depending on the availability of water) is very important for the agricultural production of the localities addressed. It would also help the use of crops adapted to the local ecosystem depending on the type of climate and soil.



(a)



(b)

Figura 6. Percentile rank P90% -P10% of the annual precipitation and the accumulated precipitation between the rainy seasons (May to October) in the localities under study: (a) Vigirima; (b) White Water.

In Agua Blanca (Figure 6b), the years 1969 and 1975 were identified as wet extremes, with annual and seasonal rainfall values higher than the 90th percentiles of the series, while the years 1974 and 1997 are considered as the dry ends of the series, being below the 10th percentile. In this case, both dry end values are higher than 800 mm, which is interpreted that under these conditions, the wet ends would have a greater impact than the dry ends.

Based on what has been described, it is necessary that this type of analysis be carried out with daily information, mainly because in the case of rainfed agriculture, the evaluation of these extreme situations requires tools that include inter-annual variability with a daily scale approach with the firm conviction to obtain a greater idea of the climatic risk in the agricultural zones.

4 Conclusions

The interannual variability of precipitation is high, even in the rainiest months. Likewise, the studies carried out show, as expected, an increase in the variability in the dry season. It is to be considered that the results shown in this study are of great importance from the point of view of the sustainable management of water for agriculture, since it implies the need to know in local detail, which are the main ranges of precipitation that have direct effects on agro-productive systems, especially when this climatic element is the most variable of the whole system.

The results showed the behavior of the seasonal and interannual variability of rainfall in a general way and its possible influence on the rainfed agriculture developed in the Lake of Valencia basin, Carabobo, with this a basic and wide knowledge about this climatic element is obtained, which will allow a much more assertive approach in making strategic decisions in agricultural territories.

The agricultural vocation in the lowlands of the lake basin of Valencia, makes it very vulnerable to persistent dry episodes, where rainfed crops such as industrial sorghum, corn, vegetables, fruit (Musaceae) and citrus reduce their yields during the absence prolonged rain, which affects the agricultural sector of the region.

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