ASPECTS OF DROUGHTS CHARACTERIZATION THE CRIȘURILOR PLAIN WITH STANDARDIZED PRECIPITATION INDEX (SPI) CALCULATED WITH THE HELP OF GAMMA AND LOG NORMAL FUNCTIONS

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Abstract

Present case study has as objectives analysis of the possibilities of agricultural drought monitoring from the center of Crișurilor Plain, using SPI values, calculatedwith Log normal and Gamma functions, highlighting the differences between the two types of values (SPI Log and SPI Gamma) and assessing conditions indicated for the use each tooth these functions with the help of correlations on the yields performed by the main crops in the area.

The influence of the two probabilistic functions on the values of SPI was studied using an experimental device consisting of three durations of drought: long (12 months) medium (6 months) and short (1 month) and 3 different lengths of periods with recordings of precipitations from Oradea, Bihor: 66 (1946-2012), 44 (1968-2012) and 22 agricultural years (1990-2012).

SPI Log normal and SPI Gamma values used to analyze agricultural droughts are different, Log normal function leading to lower values than those obtained with the Gamma function, in the negative values, exaggerates the intensity of droughts.

SPI Log normal values may be used to analyze agricultural droughts from Crișurilor Plain, when the interval of records is short (22 years) and durations of droughts long (agricultural year) or medium (cold season and warm season) when the differences between SPI Log normal and SPI Gamma are acceptable.

Key words: Standardized Precipitation Index SPI, Log normal function, Gamma function, drought intensity, drought duration, drought magnitude

INTRODUCTION

Among the many definitions of droughts, the simplest and the most suggestive is the date of Nicholson 2011, which underlines that these are encountered when the water reserve or the water supply is less than the necessary, the demand of a particular economic sector.

Through its role and functions, agriculture is a major user of natural resources, sustainable and renewable, such as water and soil including water supply, represents one of the main factors, influencing the quantity and quality of agricultural production.

According to the UN Convention "drought is a natural phenomenon that occurs when rainfall amount deposited is less than the annual average being accompanied by high temperature, which determines intense evaporation from the soil surface and reduce crop productivity" (Potop, 2003).

The existence of multiple environments (atmosphere, soil or water) and affected sectors (agriculture, industry, fisheries, hydropower, recreation - tourism, sanitation, health, etc.), the particular conditions of geographical regions and time variability of these climate hazards lead to difficult definition of some unitary indices that characterize the phenomena (Sabău, 2014).

In functions by affected environment, drought are: atmospheric or climatic, when lack of precipitations for some period of time accompanied by high air temperatures lead to a higher deficit of moisture in the air; pedological, characterized by reducing water reserve from soil; agricultural, manifested by reducing or losing agricultural productions; hydrological, characterized by reduced surface water flows and groundwater reserves; ecological, represented by the damage caused by water shortages in ecosystems; socio-economical, the economic effects of previous types (Man et al., 2010).

Whatever affected sector, the main features of droughts are: the intensity or severity, duration or period of manifestation, frequency of occurrence and their spatial extent (Cheval et al., 2003).

For monitoring the various categories of drought are using a series of droughts indices, which according to the climatic elements used for their calculation can be grouped into: pluviometric indices, using rainfall; hydro-thermic indices, precipitation and air temperature; hidro-helio-termic, precipitation, air temperature and sunshine duration; balance sheet indices, evapotranspiration, used to determine the water balance in the soil (Șerban, 2010).

The pluviometric indices used to monitor different types of droughts, including those agricultural, has the advantage that precipitation records used for calculation are widespread and accessible.

Given that the manifestation of droughts is insidious, making it difficult to determine their duration because of the weight with that it may determine the beginning and the end of them, lately imposed themselves pluviometric indices, calculated for different time periods, such as Standardized Precipitation Index (SPI).

From the mathematical point of view SPI is based on the cumulative probability of rainfall-events, over different periods of time, registered in a certain place, weather station, which is normalized using probabilistic functions Log normal or Gamma (McKee et al., 1993; Tigkas et al., 2013).

Despite the complex modality of calculation, SPI is most often used to highlight rainfall anomalies, excess or deficient, throughout the world, thanks to the possibilities of calculation with the help of computer (Krajinović, Radovanović, 2010; SPI, User Guide, 2012; Tigkas et al., 2013; Sabău, 2014).

Wu et al., 2005 mentions among the disadvantages of using SPI, for monitoring droughts the fact that his values are dependent on the length of period under review (period of rainfall records) and duration of analyzed droughts (year, month season) through the precipitation size.

Droughts monitoring with the help of SPI has been applied in several regions of Romania: Moldovan et al., 2002 in Transylvanian Depression, Șerban and Dragotă, 2009 in Eastern Plain Romania, Dragotă et al., 2012 in the Carpathians and Sub-Carpathians of Curvature, Șerban, 2010 and Hălbac-Cotora, 2013 in the Western Plain.

Sabău et al., 2015 contemplates using the Standardized Precipitation Index (SPI) and Bhalme-Mooley Drought Index (BMDI) for the monitoring of agricultural droughts from the center of West Plains, comparing their values with the yields of major crops from area, wheat and maize.

The objective of this paper is to analyze the possibilities of agricultural droughts monitoring from the center of Crișurilor Plain, using the SPI values calculated with the Log Normal and Gamma functions, highlighting the differences between the two types of values (SPI Log normal and SPI Gamma) and establish correlations between these and the yields achieved by agricultural crops in this area.

MATERIAL AND METHOD

In order to identify of periods with agricultural drought from the center of Crișurilor Plain, using the Standardized Precipitation Index (SPI) at which the normalization of precipitations cumulative distribution was done with Log normal and Gamma functions were used monthly precipitation records from Oradea Meteorological Station for the period 1946- 2012 (66 agricultural years)

Calculation of SPI values was done with DrinC program, which enables the determination of SPI values for agricultural year (Oct-Sept) using both Gamma probabilistic function and Log normal function (Tigkas et al., 2013).

To see the influence of the two probabilistic functions on SPI values, determined on different lengths periods of record, the agricultural years were analyzed on three sets of data: 66 agricultural years (1946 - 2012), 44 agricultural years (1968 - 2012) and 22 agricultural years (1990-2012).

In order to identify the droughts in the analyzed area it was determined the SPI Log and SPI Gamma for: long periods of an agricultural year (12 months); average length period of a season, cold season (Oct-Mar) and warm season (Apr-Sept) (6 months) and short periods, monthly (1 month).

The identification of long, medium and short dry periods was made by the negative values of SPI calculated in this interval, using the databases of

66, 44 and 22 agricultural years, using for the intensity characterization of scale: SPI > 0 = wet; SPI from 0 to - 0.99 = easy drought; SPI from -1 to - 1.49 = moderate drought; SPI from -1.5 to - 1.99 = severe drought; SPI ≥ - 2.0 =extremely drought (McKee et al., 1993).

For the comparisons between dry periods of different periods and of different precipitation recording period was used droughts magnitude (DM) determined by adding the negative SPI values during the dry period, with the minus sign, in order to have positive values for these:

$$DM = -\left(\sum_{j=1}^{x} SPI_{ij}\right);$$

where:

j – the first month with negative SPI values;

x – the last month of dry period;

i – the time scale in months;

As to assess possibilities for using the two indices studied, for monitoring agricultural droughts were considered the yields of the main crops of the area: wheat, maize and sugar beet, produced in the control variant, unirrigated, of the experimental field for water balance in soil from Oradea in the last 10 years of the study (Borza, 2012; Domuța, 2007; Domuţa et al., 2013).

RESULTS AND DISCUSSION

The intensity of droughts characterized by SPI values calculated with Log normal and Gamma functions

Comparing the SPI values results by the normalizing with the Log normal and Gamma functions, calculated for the duration of one year is observed that there are certain differences, positive values that characterize the rainy periods, SPI Log normal are lower than SPI Gamma. The same trend is evident in the case of negative values, characteristic for deficient in rainfall periods, which, in module are higher for SPI Log normal than SPI Gamma, indicating greater intensity of drought periods.

If we refer only to negative values given by SPI Log normal and SPI Gamma, calculated for 66, 44 and 22 agricultural years, they are larger "in module" for the Log normal function than the Gamma function, the differences it reducing from ones calculated for the period of 66 years, from 0.13 toward those calculated for the period of 22 years, these being of 0.07 (Table 1).

The same tendency remain for droughts with the average duration, of a season (6 months) and ones short, of a month, the module values increasing from long periods toward short periods.

At the same time increase the differences between the SPI Log normal and SPI Gamma values, which are of 0.24 to 0.13 for the duration of

one season, and form 1.56 to 0.52 for the drought duration of one month, respectively.

Table 1

The maximum intensity of drought periods after SPI calculated with Log normal and Gamma functions

Period of precipitations registration (agricultural years)		SPI Log normal			SPI Gamma		
		The duration of droughts (months)			The duration of droughts (months)		
		12	6	1	12	6	1
1946-2012	66	-2,28	-2,60	-6,09	-2,15	-2,38	-4,53
1968-2012	44	-1,97	-2,66	-5,42	-1,87	-2,42	-4,22
1990-2012	22	-1,71	-2,50	-4,26	-1,64	-2,37	-3,74

The biggest differences between SPI Log normal values and SPI Gamma were recorded for December, analyzed during 1946 - 2012 (66 agricultural years) maximum SPI Log normal value being of - 6.09 compared with SPI Gamma value, of -4.53 in the agricultural years 1972-1973 (Fig. 1).

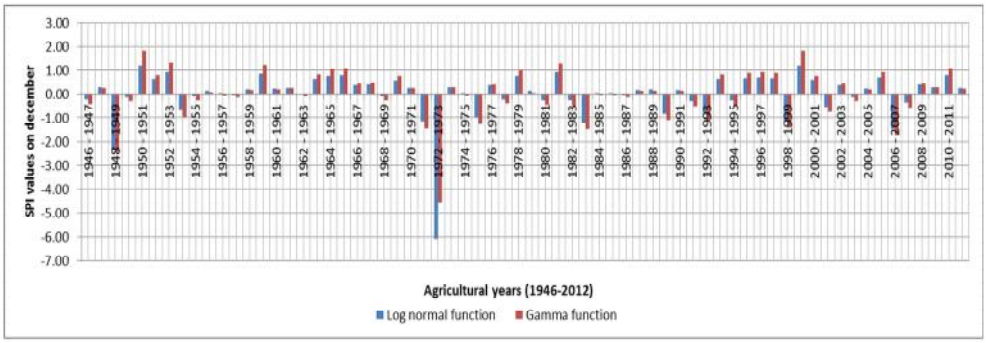

Fig. 1. The SPI values from December, on 66 years, calculated with Log normal and Gamma functions

Given the vast differences between the SPI Log normal and SPI Gamma values, for long periods of analysis and shorter durations of droughts, the fact that the function Log normal lead to lower values than those obtained with the Gamma function, which exaggerates the intensity of droughts, we believe that these values can be used to droughts analyze, when the records period is short and for long (year) or medium (season) periods of droughts, when differences between SPI Log normal and SPI Gamma are acceptable.

Correlations between SPI Lognormal and SPI Gamma values with agricultural production from Oradea (2002-2012)

The correlations established between SPI values, calculated with the two functions and agricultural production of wheat, maize and sugar beet,

obtained in the last 10 years of the analyzed period (2002-2012), in the control variants of water balance in the soil field, located adjacent to the meteo station have statistical significance, does not depend on the records period of date, correlation coefficients being close (Table 2).

Table 2

Correlation between SPI Log normal and SPI Gamma values with agricultural production of wheat, maize and sugar beet (Oradea, 2002-2012)

Period	The duration of droughts	SPI Log normal		SPI Gamma	
		Correlation coefficient R	Statistical significance	Correlation coefficient R	Statistical significance
Wheat					
1946-2012	Agricultural year	0,7772	**	0,7816	**
	Cold season	0,8674	**	0,8571	**
1968-2012	Agricultural year	0,7773	**	0,7817	**
	Cold season	0,8674	**	0,8570	**
1990-2012	Agricultural year	0,7773	**	0,7817	**
	Cold season	0,8674	**	0,8571	**
Maize					
1946-2012	Agricultural year	0,7364	*	0,7594	*
	Warm season	0,6127	-	0,6301	*
1968-2012	Agricultural year	0,7363	*	0,7595	*
	Warm season	0,6129	-	0,6103	*
1990-2012	Agricultural year	0,7363	*	0,7593	*
	Warm season	0,6129	-	0,6301	*
Sugar beet					
1946-2012	Agricultural year	0,8354	**	0,8363	**
	Warm season	0,9472	***	0,9385	***
1968-2012	Agricultural year	0,8353	**	0,8364	**
	Warm season	0,9472	***	0,9385	***
1990-2012	Agricultural year	0,8553	**	0,8363	**
	Warm season	0,9472	***	0,9385	***

These correlations are distinct significant for wheat, both for SPI Log normal values and SPI Gamma values, calculated for the agricultural year and for the cold season, Least Significant Differences (LSD) being less than 1%.

Maize yields simulated in the same conditions show statistically significant correlations for the values recorded in agricultural years, for both categories of values, while in the warm season, only correlation with SPI Gamma values have statistical significance within 5 % error (LSD 5%).

The closest statistical links are obtained from sugar beet, both for the agricultural year and for warm season, which are very significant statistically for both the values of SPI Log normal and SPI Gamma (Fig. 2).

The frequency of long, medium and short dry periods determined after SPI Log normal and SPI Gamma values

The drought frequency of various durations, calculated for different periods is estimated by the percentage of negative SPI values, determined by normalizing with the above mentioned functions.

For large durations of droughts, their frequency determined by SPI Log normal and SPI Gamma is the same, when using strings of 66 (57.6 %) and 44 years (54.6%) of rainfall records. If the record period is of 22 years (1990-2012) SPI Log normal lead to the same frequency of droughts to that obtained during 1968-2012, while the SPI Gamma indicates a frequency of 59.1 %, higher than the frequency resulting by analysis of 44 years to + 4.8 % (Table 3).

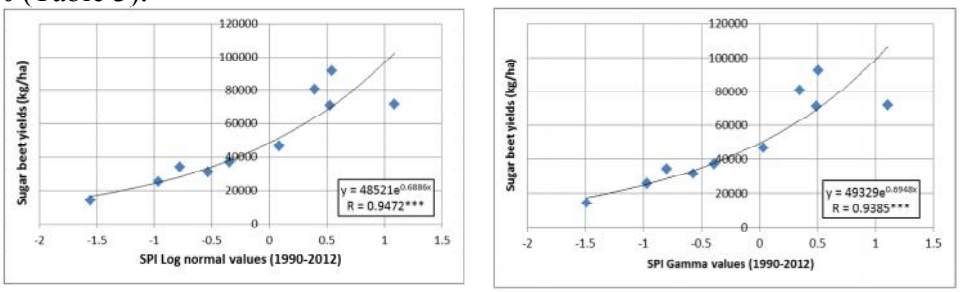

Fig. 2. Correlations between SPI Log normal and SPI Gama values from warm season and sugar beet yields (2002-2012)

Table 3

The frequency of droughts (%) after SPI (negative values) calculated with Log normal and Gamma functions

Period of precipitations registration (agricultural years)		SPI Log normal			SPI Gamma		
		The duration of droughts (months)			The duration of droughts (months)		
		12	6	1	12	6	1
1946 - 2012	66	57,6	46.2	41,5	57,6	49.2	45,7
1968 - 2012	44	54,6	48,9	42.2	54,6	48,9	46.0
1990 - 2012	22	54,6	45,5	41,7	59,1	47,7	46,2

For the average and small durations of droughts, values SPI Gamma indicates higher frequencies of dry periods, regardless of the size of the analyzed period, excluding the frequency of average droughts, with length of 6 months, which is the same for the two functions during 44 years (1968 - 2012) probably because the period 1968-1990 was rainiest.

In the case of May, the biggest frequency differences of droughts with short duration are registered on the interval of 22 agricultural years, the dry months have a frequency, after SPI Log normal only 40.9 % and after SPI Gamma of 50.0 % (Fig. 3).

It may be noted that the differences of droughts characterization in May appear only in "wet", the SPI Log normal values indicating a

frequency of wet months of 59.1 %, while SPI Gamma of 50 %, which are netted at the frequency of easy dry months, that is 22.7 % for Log normal function and 31.8 % for Gamma. In the zone of the months characterized as moderately and severely dry, their frequencies are equal, lacking in both cases extremely dry months.

Although the intensity of droughts is higher for SPI Log normal than for SPI Gamma, the frequencies of droughts, are greater when their appreciation is make with SPI Gamma, especially of short duration droughts, making it possible the development of some differences in the thereof intensity characterization.

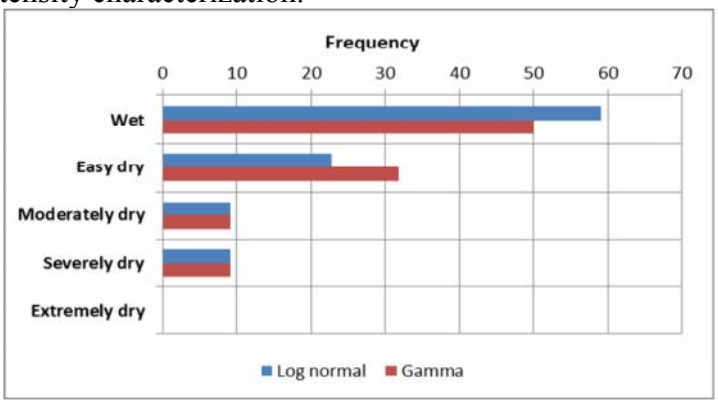

Fig. 3. The characterization frequency of droughts in May after SPI, calculated with Log normal and Gamma functions for a period of 22 agricultural years (1990-2012)

The maximum duration of droughts (months)

The maximum duration of droughts from an agricultural year or season is determined by the number of consecutive months with negative SPI values. Although SPI Log normal values indicate higher intensities of droughts, the maximum duration is less than in the case of its determination using SPI Gamma values.

Average duration of annual droughts, analyzed for the period 1990-2012, indicated by SPI Log normal is 1.77 months, while that resultant with SPI Gamma is 2.18 months (Fig. 4).

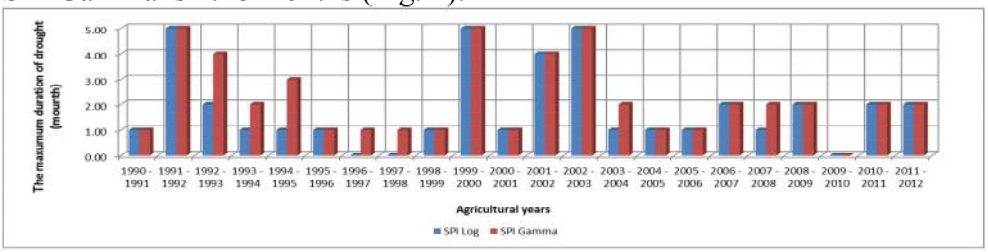

Fig. 4. The maximum duration of droughts (months) of the warm season (1990-2012)

The maximum duration of droughts is dependent on the length of analyzed droughts. For the same period the number of periods with

consecutive dry months increases from the records of 66 years to the short records of 22 years.

Droughts magnitude (DM)

The magnitude of droughts (DM) is a synthetic indicator of droughts that integrating the intensity of droughts and their duration, expressed by the sum of negative values module from the dry months of the period analyzed, an agricultural year or a season.

Although SPI Log normal values have the module of the negative values greater than SPI Gamma values, it determines the average magnitudes of seasonal droughts smaller (2.11 - 2:27) than in the case of the seasonal magnitude results by SPI Gamma (2.29 - 2.35). The situation is the same for the magnitude of annual droughts (Table 4).

Table 4

Annual and seasonal droughts magnitude, depending on the length of precipitation records and the used probabilistic normalization function

Period of precipitations registration (agricultural years)	SPI Log normal						SPI Gamma					
	Cold season		Warm season		Agricultural year		Cold season		Warm season		Agricultural year	
	Med	Max	Med	Max	Med	Max	Med	Max	Med	Max	Med	Max
1946-2012	2,11	10,5	2,23	8,4	4,34	12,3	2,30	8,4	2,32	7,1	4,62	10,7
1968-2012	2,13	9,9	2,20	8,0	4,33	12,0	2,29	8,1	2,30	7,2	4,59	10,7
1990-2012	2,27	7,4	2,26	6,6	4,53	9,3	2,35	6,9	2,34	6,5	4,69	9,2

In the case of the maximum magnitudes, the situation is reversed, regardless of the period, ones calculated with SPI Log normal are always higher than those calculated with SPI Gamma, which are between 6.6 and 12.3 for Log normal function and between 6.5 and 10.7 for the Gamma function, respectively.

The influence of drought magnitude SPI Log normal and SPI Gamma on wheat, maize and sugar beet yields

Annual and seasonal droughts magnitudes determined in the last 10 years of analyzed period, differentially affects the formation of agricultural production of the main three crops from area (Table 5).

For wheat crop the magnitudes of annual droughts influences significantly distinct (LSD 1 %) the productions; the magnitudes of cold season influences significantly (LSD 5 %) productions, except those laid for the period of rainfall record of 22 years when they become significantly distinct, while the correlations with droughts magnitude from the warm season do not show statistical significance.

In maize the production simulation by means of seasonal magnitudes, do not have statistical significance, neither for the cold season neither for the warm season and in the case annual magnitude, only wen that was determined by long periods of records of 66 years.

The yields of sugar beet are correlated significantly distinct (LSD 5%) with magnitudes of annual droughts and with those of droughts from warm season, less for a situation where they are determined using a number of short records of rainfall for years of 22.

It may be worth noting that for wheat crop the correlation coefficients of annual magnitude increase for both probabilistic functions applied, from long periods of rainfall records of 66 years (1946-2012) at shorter records periods than 22 years.

Table 5

The influence of droughts magnitude determined by SPI Log normal and SPI Gamma values on the agricultural productions of wheat, maize and sugar beet, Oradea, 2002-2012

Period	The duration of droughts	SPI Log normal		SPI Gamma	
		Correlation coefficient R	Statistical significance	Correlation coefficient R	Statistical significance
Wheat					
1946-2012	Agricultural year	0,7989	**	0,8694	**
	Cold season	0,7397	*	0,7626	**
1968-2012	Agricultural year	0,7721	**	0,8512	**
	Cold season	0,7348	*	0,7685	**
1990-2012	Agricultural year	0,8638	**	0,8794	**
	Cold season	0,7956	**	0,7878	**
Maize					
1946-2012	Agricultural year	0,6284	*	0,6544	*
1968-2012	Agricultural year	0,6180	-	0,6274	-
1990-2012	Agricultural year	0,5255	-	0,5503	-
Sugar beet					
1946-2012	Agricultural year	0,7711	**	0,7810	**
	Warm seson	0,7954	**	0,8174	**
1968-2012	Agricultural year	0,7382	**	0,7602	**
	Warm seson	0,7857	**	0,8021	**
1990-2012	Agricultural year	0,7199	*	0,7457	*
	Warm seson	0,7028	*	0,7547	*

The best simulations of wheat production, from the period 2002 - 2012 are obtained by annual droughts magnitudes, determined for the period 1992-2012, which are for both tested functions distinct significant (Fig. 5).

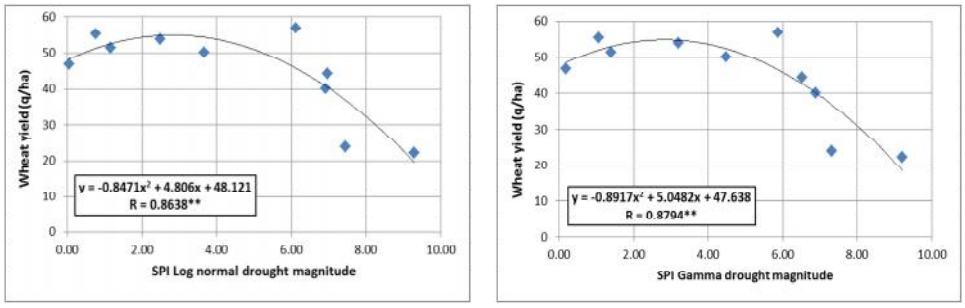

Fig. 5. The influence of annual drought magnitude on wheat yields, Oradea 2002-2012

Although the statistical significance of correlative links are the same for all cultures, both for magnitudes of droughts determined by SPI Log normal as well as those determined by SPI Gamma, the correlation coefficients are somewhat higher in the case of the magnitude calculated by Gamma SPI values.

CONCLUSIONS

Between the SPI Log normal and SPI Gamma values were highlighted differences, regardless of the precipitation recording period and duration of droughts analyzed, the normalization with Log normal probabilistic function lead to lower values, which in the negative zone of values, exaggerates the intensity of droughts.

Drought frequencies are higher, in the case of their appreciation using SPI Gamma values, especially the droughts of short duration, being influenced the characterization their intensity. For the same duration of droughts number of periods with consecutive dry months increases from the longer record periods of 66 years to ones short of 22 years. SPI Log normal values determine average magnitudes of seasonal droughts smaller (2.11 to 2.27) than the average magnitudes of seasonal droughts, obtained with SPI Gamma (2.29 to 2.35).

Statistical significances of correlative links between drought intensity and their magnitude, calculated with SPI Log normal and SPI Gamma are generally the same for all cultures, the correlation coefficients being higher for the magnitude calculated by the SPI Gamma values.

SPI Log normal values may be used to agricultural droughts analyze when the interval records is short (20-30 years) and the drought durations are long (year) or medium (season), when differences between these and SPI Gamma are acceptable.

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