Rainfall Variability and Soybean Yield in Paraná State, Southern Brazil

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Abstract— *Agriculture (the agricultural exports flagship from southern Brazil) is highly dependent on temporal rainfall distribution. However, the technology used in the field has been altering this relationship. Such technology, in addition to minimizing the effects of climate variability, has increased the annual soybean yield observed in the trend analysis, which was positive in 17 of the municipalities studied. The aim of this study was to analyze the rainfall variability and soybean production in one of the areas of greatest soybean production in southern Brazil by applying the quartile, percentile, Pettitt (homogeneity - break results) and Mann-Kendall (trend) tests. The results indicate a significant relationship between annual rainfall variability (1999-2000; 2009-2010) and soybean yield (kg/ha), particularly during the growing season of 2009-2010 when the yield variation between municipalities was low. It was concluded that the statistically significant correlations indicate that the soy dependence ranges from 22% to 50% in certain municipalities.*

Keywords— Rainfall variability, agriculture, soybean, agricultural climatology, southern Brazil.

I. INTRODUCTION

The potential impact of climate change on agricultural production has often been evaluated on national and regional scales. In much of the tropics, rainfall is the main factor responsible for annual fluctuations in the grain yield. Between 60% and 70% of agricultural production is explained by interannual rainfall variability (Camargo 1984; Göpfert et al. 1993; Pereira et al. 2002; Goldblum 2009).

A correlation analysis by Krishna Kumar et al. (2004) described indicators of the effects of monsoonal rains and its potential (surface temperatures and sea level pressures in the Pacific and Indian Oceans) to affect in agricultural yield in India. The conclusion was that there is a significant correlation between the total annual yield in India (except for sorghum and sugarcane) and the total rainfall during the summer monsoon.

Goldblum (2009) reported that corn yield in the United States is negatively correlated with the temperatures in July and August in much of the state of Illinois and positively correlated with rainfall in September (in the central portion of the state) and rainfall in July and August in most of southern and northern Illinois. The soybean yield is negatively correlated with the mean monthly temperature in central and southern Illinois during the summer and positively correlated with rainfall in July and August in the same regions.

Penalba et al. (2007) analyzed the impacts of climate variation on agriculture in the primary agricultural region of Argentina, the Pampas. Simple correlations between certain variables quantitatively confirm that the air temperature and rainfall are the main climate factors that determine the variation in agricultural production.

Farming practices in Brazil have changed in the last 30 years, particularly with regard to agricultural modernization and techniques for minimizing climatic influences on productivity (Assunção 2002; Wilhelmi et al. 2002).

In developing countries, the relationship between the annual production of some commodities and droughts is often considered by researchers in the biological and natural sciences due to the agricultural conditions in these countries. After all, droughts can seriously affect the growth and development of plants (Rodrigues et al. 2015). These concerns are observed in countries in which capitalism is peripheral, which are more vulnerable to droughts because there is less investment in technology to minimize these effects; they are derived from policies focused on grain yield and justified by the need to produce food. Therefore, losses and annual fluctuations in the yield of grains such as soybeans economically impact the manufacture of many other products.

Almeida and Sant'Anna Neto (2007) concluded that in Brazil, particularly in the states of Rio Grande do Sul, Paraná and Mato Grosso, the soybean yield is correlated with and depends on the rainfall, which is increased in subtropical latitudes and decreased in tropical ones.

Because soybeans are one of the most important agricultural products in the world (Rodrigues et al. 2015) and are currently acquiring a central role in food security and the world food demand (Sentelhas et al. 2015), the aim of this study was to analyze the rainfall variation and its impact on soybean productivity during the growing season of October to April in producing areas in the state of Paraná, southern Brazil, during the agricultural years of 1999-2000 to 2009-2010.

1.1 Soybean physiology and phenology

The soybean (Glycine max) grown in Brazil for grain production originated in China. It is an herbaceous plant with a hispid stem, is sparsely branched, and has roots on a main axis and many branches. It has trifoliate leaves and white, purple or intermediate color flowers, developing slightly arched pods that, as they grow, change from green to pale yellow, brown or gray and may contain from one to five seeds (Nepomuceno et al. 2001; Farias et al. 2009).

It is an annual plant classified into maturity groups based on its life cycle, which can range from 70 to 180 days from emergence to maturity. Depending on the environmental conditions and variety, the plant height varies, but is ideally between 60 and 110 cm because plants of this size can facilitate mechanical harvesting and prevent lodging. Flowering also varies: soybean is a short-day plant, and its flowering is delayed on long days. The soy planted in Brazil is not in its native environment due to its tropicalization (Almeida 2005; Farias et al. 2009).

In addition to water and temperature requirements, adaptation of different soybean cultivars to certain regions depends on its photoperiodism. Photoperiod sensitivity is a variable that is characteristic of cultivars; that is, each cultivar has a critical photoperiod (CP) above which flowering is delayed. For this reason, soy is considered a short-day crop (Almeida 2005; Farias et al. 2009). Soy can be grown under highly variable environmental conditions and is grown predominantly without irrigation. Thus, it is subject to drought, which may affect plant development (Confalone and Dujmovich 1999).

The need for water increases with the development of the plant, reaching a maximum during the period of flowering and grain filling (7 to 8 mm/day) and decreasing afterward. The total water requirement for optimum yield ranges from 450 to 800 mm/cycle, depending on weather conditions, crop management and cycle time. Plants under water stress are affected by difficulty with water absorption, seed germination, stomatal closure, transpiration, photosynthesis, enzyme activity, nitrogen metabolism, and other processes (Awad and Castro 1989; Berlato and Fontana 1999; Matzenauer et al. 2003).

There are two developmental periods during which the availability of water is very important: germination-emergence (VE) and flowering-grain filling (R5) (Fig. 1). In germination, both an excess and a lack of water are harmful to uniformity in plant population stands because the seed needs to absorb at least 50% of its weight in water for good germination. During this period, the soil water content should not exceed 85% of the total available water nor be less than 50%.

A significant lack of water during flowering leads to physiological changes in the plant, such as stomatal closure and leaf rolling, and consequently, premature fall of flowers and leaves and pod abortion, which ultimately lead to a reduction in grain yield (Koslowski 1968; Nepomuceno et al. 1993; Embrapa, 2006). Insufficient soil water is considered one of the most common causes of poor soybean seed germination in areas susceptible to water deficits at the beginning of the planting period. Soybean seeds are in a state of constant moisture exchange with the surrounding air, seeking hygroscopic equilibrium (Peske and Delouche 1985; Ahrens and Peske 1994).

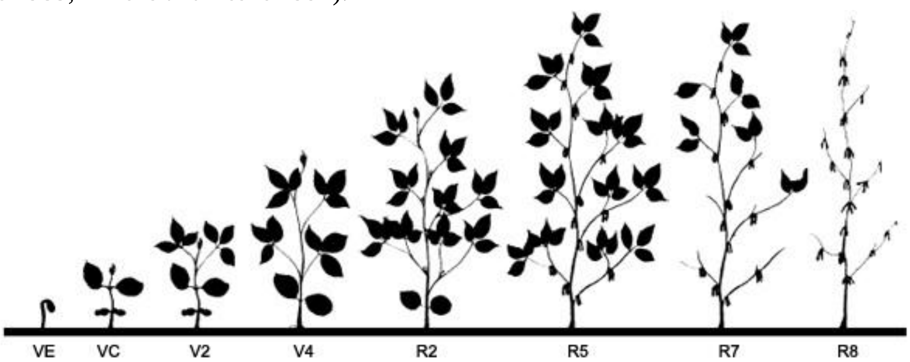

FIG. 1 PHENOLOGICAL STAGES OF SOYBEAN. VE = EMERGENCE, VC = COTYLEDON, V1 = FIRST NODE, V2 = SECOND NODE, V4 = FOURTH NODE, R2 = FULL BLOOM, R5 = START OF GRAIN FILLING, R7 = EARLY MATURITY, AND R8 = FULL MATURITY. SOURCE: IOWA STATE UNIVERSITY

1.2 Climate characteristics of the study area

Soybean production in tropical and subtropical areas of Brazil is concentrated in two regions: Paraná state in southern Brazil and Mato Grosso state in midwestern Brazil (Flaskerud 2003). Southern Brazil, particularly in the Paranapanema River basin, contains an area of intense soybean cultivation that measures approximately 55,000 km . The altitude of this region of Paraná varies between 223 m and 1356 m (Fig. 2).

The state of Paraná is the second largest Brazilian region that produces and sells grains, mainly soybeans. On the south branch of the Paranapanema river basin, which is inserted in this context, are some of the major grain-producing municipalities of the state, including Londrina, Maringá, Castro, Paranavaí, and Ponta Grossa, which are marked by modern agriculture and high levels of mechanization and are inserted in international agribusiness.

However, in this same region, there are municipalities that do not participate in agribusiness because they are characterized by another agrarian reality, which is marked by the presence of small family farms, and land conflict areas in which the Landless Workers' Movement (Movimento dos Trabalhadores Sem Terra - MST) has a strong presence. This applies to the north and northwest portions of the study area, including the municipalities of Loanda and Querência do Norte (Carmello and Sant'Anna Neto 2015).

Because of its location in a climate transition area along the Tropic of Capricorn, the northern portion of the basin is generally tropical, with marked alternation between the dry (winter) season and rainy (summer) season. The central and southern portions are subtropical with a more uniform rainfall distribution throughout the year (Mendonça and Stipp 2000).

The rainfall variation in Paraná is essentially determined by the intensity of the high-pressure Subtropical Highs (Altas Subtropicais de alta pressão - ASAS), cold and dry polar anticyclones (mP), hot and humid equatorial systems from the Amazon (mEC), tropical systems from the South Atlantic (mTA) and hot and dry tropical continental systems. In this regional context, the temporal variation in rainfall is a result of large-scale interactions between systems connected to the South Atlantic Convergence Zone (SACZ), the extra-tropical pressure systems and the mesoscale convective systems (MCS) (Mendonça and Stipp 2000; Souza 2006; Grimm 2009; Nascimento et al. 2014).

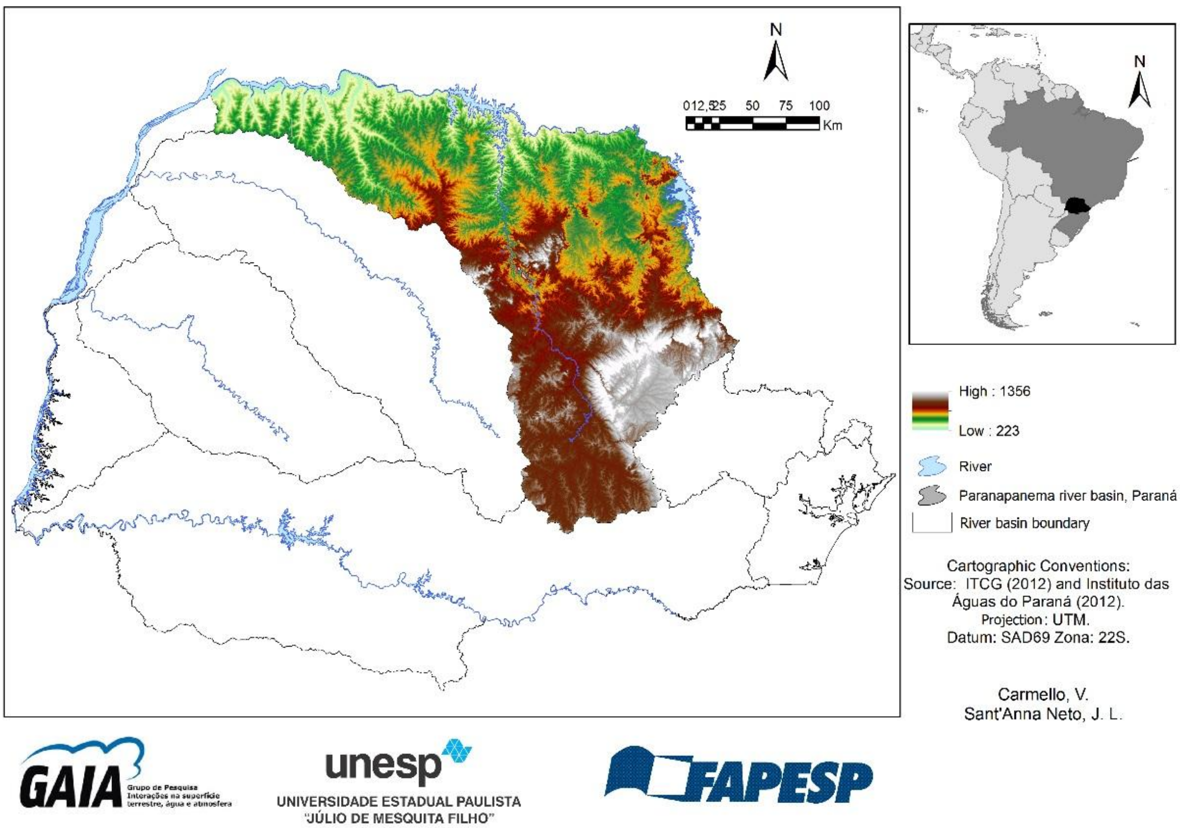

FIG. 2 LOCATION AND RELIEF OF THE PARANÁ SLOPE OF THE PARANAPANEMA RIVER BASIN, BRAZIL

II. MATERIAL AND METHOD

The daily rainfall data were provided by the Water Institute of Paraná (Instituto das Águas do Paraná), which maintains a network of 154 rainfall stations evenly distributed across the study area. Of these, 89 rainfall stations exhibited consistent historical series (Fig. 3) corresponding to the growing seasons (October to April) from 1999 to 2010. To analyze the rainfall variation during this period and identify the extreme rainfall years, the quantile technique (percentile) of cumulative rainfall was used. Williams-Sether et al. (2004), based on Huff (1990), used the percentile technique to classify storms into four classes. For this study, we opted to divide the percentiles into five classes so that records of extreme rainfall values could be disclosed. This technique was performed using Microsoft Excel. Annual averages were obtained using the following formula by Armond (2014):

$$Q\ (P) - Yt + \left[\frac{P - P_i}{P_{(+)} - P_i}\right](Y_{i+1} - Y_i)$$

where Yi is the station average, P is the percentile, and Pi is the station number/total number of stations + 1. The values were normalized by m to obtain values between 0 and 1 (Silvestre et al. 2013). Based on the calculated percentiles, five rainfall classes were established: extremely dry (below 0.10), dry (between 0.10 and 0.35), normal (between 0.35 and 0.65), rainy (between 0.65 and 0.90), and extremely rainy (above 0.90) (Carmello et al. 2014). The following classes of annual rainfall based on their percentile rankings were developed: 90th and above (extremely rainy years), 65th to 90th (rainy), 35th to 65th (normal), 10th to 35th (dry) and 10th and below (extremely dry). The selection of class intervals of various amplitudes from among these data was based on the need to identify the most extreme standard years because the severity of extreme climate events significantly impacts nature and society (Zhang et al. 2009; Armond 2014). Thus, the 90% and 10% thresholds were used to identify the extremely rainy and extremely dry seasons of the series. These class intervals of various amplitudes were displayed in a space-time framework, with each year and values differentiated by colors (Meisner 1976; Sant'Anna Neto 1990; Mousinho et al. 2004).

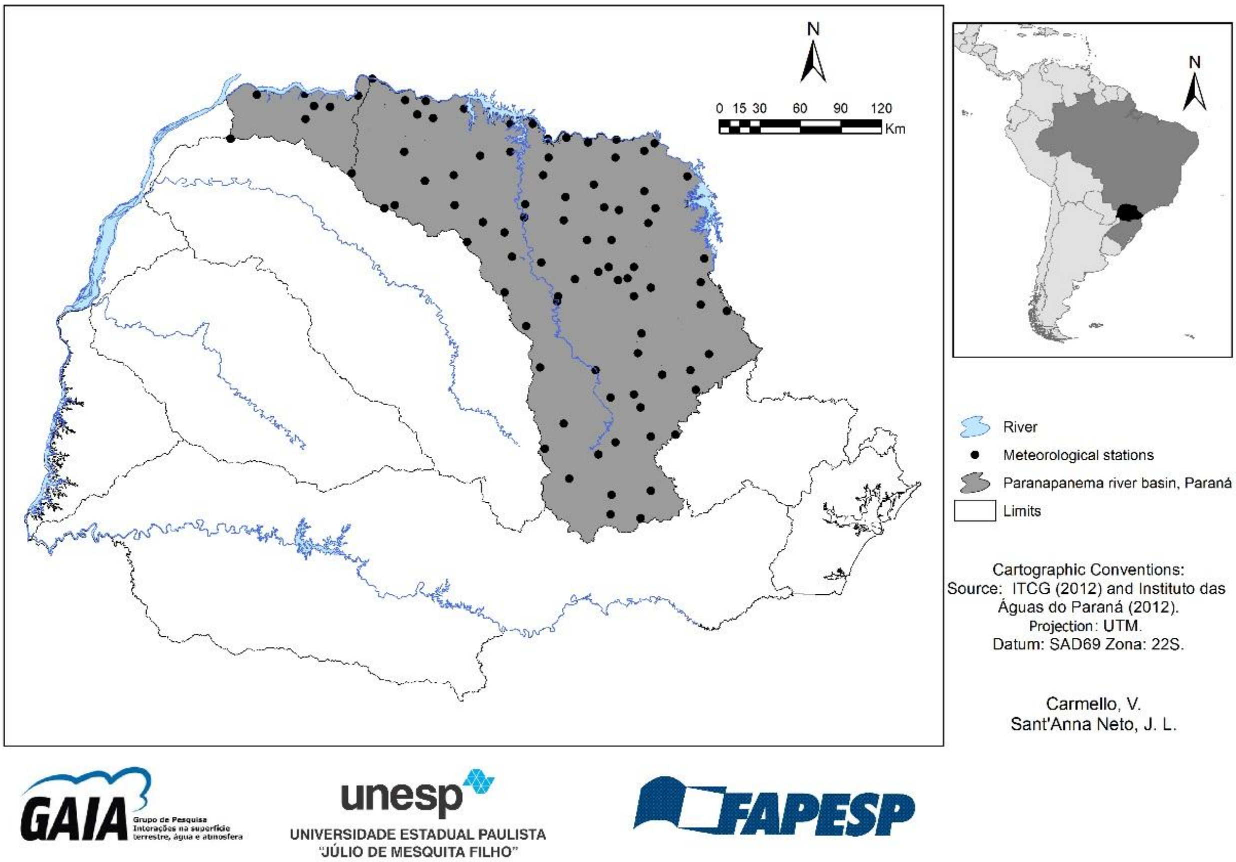

FIG. 3 LOCATION OF EIGHTY-NINE RAINFALL STATIONS ON THE PARANÁ SLOPE OF THE PARANAPANEMA RIVER BASIN

Two statistical techniques were applied using the software product XLSTAT®: the Pettitt test and the Mann-Kendall test. For analyzing the yield data, only the Mann-Kendall test was used. These techniques were selected to verify the consistency levels of the historical series with regard to the data homogeneity and to identify any statistical trends (positive or negative correlations) in the records spanning a given period. The Pettitt test operates on a time series (Moraes et al. 1995) and is represented by the formula

$$t_n = \sum_{i-1}^{n} m_i$$

The statistical significance was tested with a null tn using a two-tailed test, which can be rejected for large values of u(t), given by the equation

$$u(t) = \frac{(t_n - E(t_n))}{\sqrt{Var(t_n)}}$$

The Mann-Kendall test is used to evaluate the null hypothesis, i.e., whether there is a trend in the series, in addition to three other hypotheses: a negative trend, no trend and a positive trend. The Pettitt test is based on a version of the Mann-Whitney test, which is used to check whether two samples, X and Xt,…, Xt+ 1, …, Xt are from the same population, that is, whether all years of the historical series belong to the same class (Pettitt 1979; Moraes et al. 1995; Tian et al. 2012); it can be written as follows:

$$U_{t,T} = U_{t-1,T} + \sum_{j=1}^{T} sgn\,(X_{i-}X_j)$$

where sgn(x) = 1 for x > 0, sgn (x) = 0 for x = 0, and sgn (x) = - 1 for x < 0. The Ut,T statistic is calculated for values t such that of 1 ≤ t ≤ T, and the k(t) from the Pettitt test is the maximum absolute value of Ut,T (Moraes et al. 1995) such that

$$K(t) = MAX_{1 \le t \le T}\, U_{t,T}$$

2.1 Data and procedures for measuring the annual soy variation

The yield and planted area data collected from 132 municipalities and entirely or partially spanning the period of 1999-2010 were used. The yield for each municipality was calculated by dividing the total produced amount by the total cultivated area (Secretary of the Paraná State Supply - SEAB – Secretaria de Abastecimento do Estado do Paraná). The soybean yield data were processed and analyzed based on the annual total. To analyze the data variation, boxplot graphs were used. This type of graph, a box plot, is well known in statistics, and most statistical software has a function for it.

The boxplots divide each homologous series into quartiles: Q1 is the 25th percentile, Q2 is the median that divides the series into two equal parts, and Q3 is the 75th percentile (Carmello 2013; Silvestre et al. 2013). The line in the center of the rectangle represents the median, the bottom of the rectangle represents the first quartile (Q1), and the top of the rectangle represents the third quartile (Q3). From Q3, a line that extends to the highest observed value of the variable is shown, provided it does not exceed the upper limit, LS=Q3+1,5(Q3-Q1). Below Q1, there is another line that extends to the lowest observed value of the variable, provided it does not exceed the lower limit, LI=Q1-1,5(Q3-Q1). Asterisks represent extreme values in the sample, also known as outliers, which exceed the upper or lower limits (Silvestre et al. 2013).

2.2 Statistical Correlation

Pearson's coefficient was used to correlate the rainfall and yield data. This linear correlation coefficient does not imply a cause-and-effect relationship but rather is a measure of the strength of a linear relationship between two variables. This coefficient of variation r is a value ranging from -1 to 1, where a value of 0 represents the absence of a linear correlation. To obtain α, with r significance, the t test was applied, considering at least α = 0.05 (Toledo and Ovalle 2008). Falcão (2012) explained that the correlation between two variables in the context of a time series measures the degree of correlation relative to the direction of evolution of the values represented by each variable over time.

III. RESULTS AND DISCUSSION

Table 1 summarizes the results of the Pettitt (homogeneity) and Mann-Kendall (trend) tests The results indicate that the historical data series is homogeneous: according to the Pettitt's text, only 3 rainfall stations present statistical breaks (Fig. 4). Based on the Mann-Kendall test (increasing or decreasing trend), of the 89 analyzed stations, 13 stations displayed a trend of increasing rainfall, 76 displayed no statistically significant trend, and none displayed a negative trend. These results demonstrate two different typologies.

TABLE 1
SUMMARY OF BREAK RESULTS, PETTITT TEST AND TREND, MANN-KENDALL

Test type	Break or Positive Trend	Break or Negative Trend
Pettitt	3	86
Mann-Kendall	13	76

None of the stations in the southern portion of the water basin displayed a significant trend in rainfall. In the north-central section, 85% of the stations displayed neither positive nor negative trends in rainfall, and 15%, located primarily in the Tibagi River sub-basin, displayed a positive trend (Fig. 5).

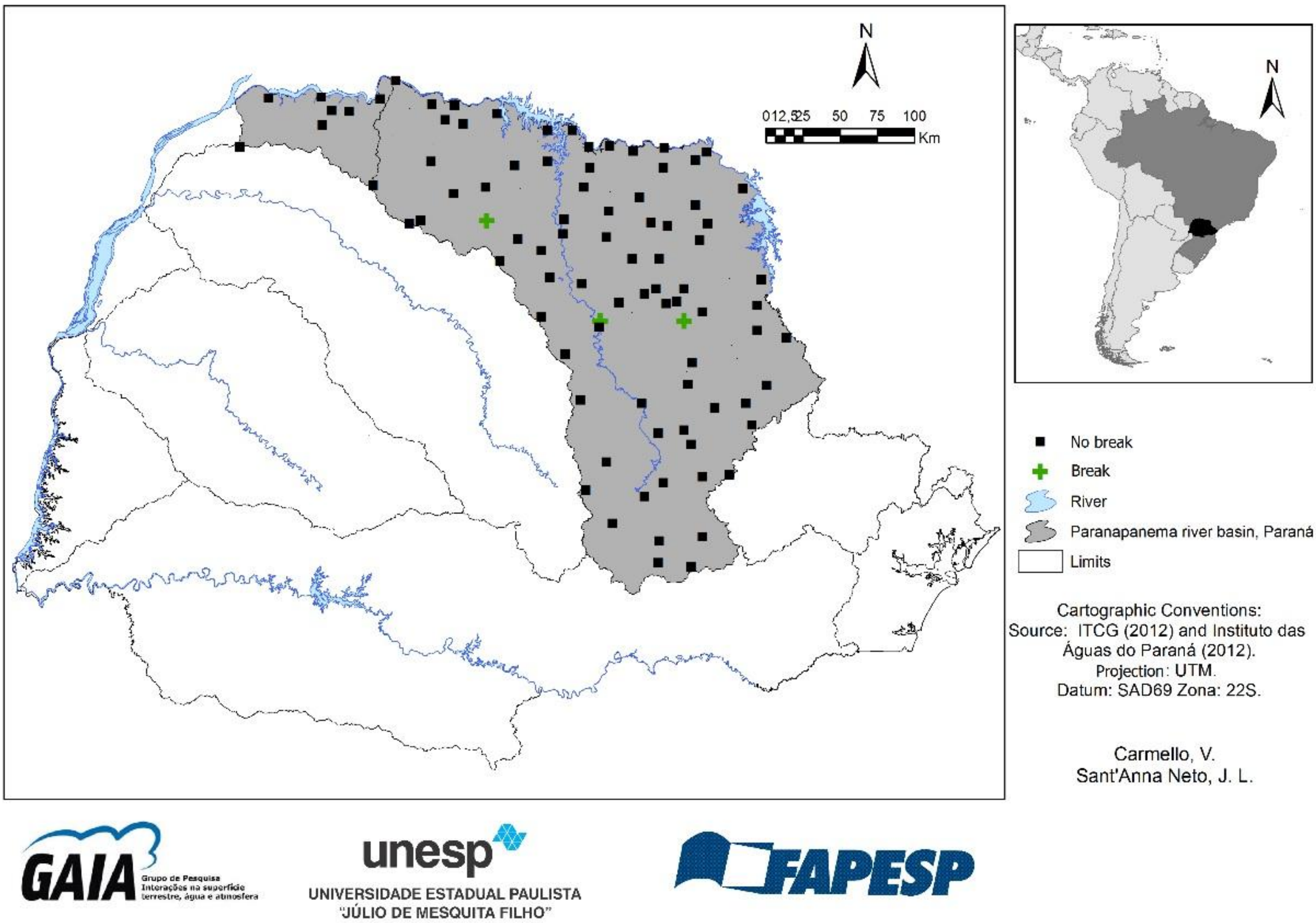

FIG. 4 RESULTS OF THE PETTITT TEST, WITH THE STATIONS WITH NO BREAK IN THE SERIES OR WITH POSITIVE BREAK

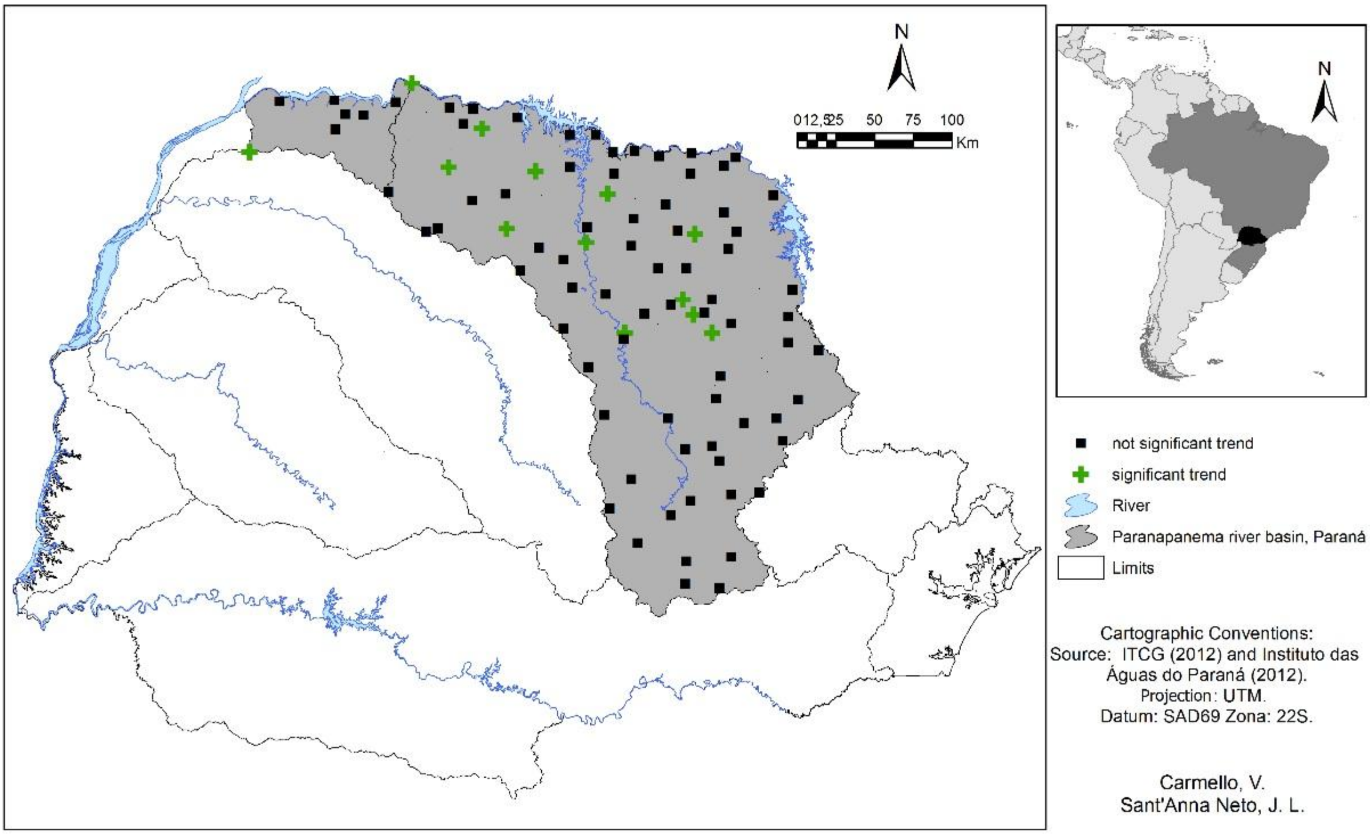

FIG. 5 RESULT OF MANN-KENDALL TEST, STATIONS WITH NO TREND OR POSITIVE RAINFALL TREND

3.1 Interannual rainfall variability

The average annual rainfall in the study area ranges from 1,300 to 1,800 mm, of which approximately 70% is concentrated in the rainy season (from October to April) in the northern portion and approximately 60% in the southern portion. The use of the percentile technique indicates strong interannual variability in the rainfall, accurately highlighting the extremely dry and extremely rainy years. For a closer analysis of what was defined as extreme, a division into five classes was used: extremely dry, dry, normal, rainy and extremely rainy years. Both spatial and temporal distributions of these results are presented in tables 2.

In Table 2, the annual soybean crop data are shown (columns), as are rainfall stations (classes in rows by latitude). A dry pattern is noted in the first three years of the series, especially at rainfall stations located at lower latitudes. There is a well-defined pattern that varies from habitual to rainy from 2004-2005 to 2007-2008 (Carmello and Sant´Anna Neto 2015). A rainy pattern can be seen in the 2002-2003 agricultural year; however, in the following year, 2003-2004, lower rainfall levels predominated, especially at lower latitudes, indicating a dry or very dry pattern. The 2009-2010 agricultural years were the rainiest of the historical series; in it, 88 of the 89 rainfall stations recorded extremely humid values.

TABLE 2
INTERANNUAL RAINFALL VARIATION BY YEAR AND LOCATION OF RAINFALL STATION

Latitude	Longitude	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	Latitude	Longitude	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
22º 39' 39"	52º 07' 59"	-21	1	-15	33	-38	6	5	15	-14	-14	43	23º 24' 50"	49ב 58' 51"	-37	-13	8	12	3	11	-12	2	13	-12	24
22º 33' 03"	52º 02' 11"	-25	-15	-20	22	-17	0	-15	21	6	-9	53	23º 24' 34"	50º 21' 30"	-16	-42	-19	11	-11	6	6	47	16	-29	31
22º 44' 04"	52º 20' 38"	-13	-18	-9	13	-22	12	4	29	21	-41	26	23º 49' 09"	50º 19' 44"	-37	-41	-9	19	13	-3	-34	3	12	13	64
22º 39' 15"	52º 51' 38"	-42	-10	31	23	-14	-5	9	10	-1	-27	26	23º 12' 00"	51º 27' 00"	-12	-4	-23	16	-30	-8	-14	13	6	12	45
22º 39' 10"	52º 31' 05"	-30	-8	1	22	-20	7	26	-4	8	-42	39	23º 30' 00"	50º 39' 00"	-32	2	0	1	-11	18	-8	11	-11	-1	30
22º 57' 35"	50º 46' 16"	-5	-6	-20	11	-23	6	-10	19	18	-22	30	23º 45' 00"	51º 01' 36"	-6	-7	-24	19	-10	4	-15	9	3	13	11
22º 51' 04"	50º 52' 28"	9	-9	-23	12	-46	10	7	22	-5	-23	48	23º 45' 00"	51º 01' 36"	-27	9	2	17	1	-9	-32	30	1	-5	14
22º 49' 05"	52º 31' 00"	-15	-20	-16	20	-18	-14	6	26	28	-35	38	23º 53' 18"	50º 11' 04"	-26	4	-19	16	-30	20	2	9	-13	-16	53
22º 51' 06"	51º 01' 55"	3	-15	-19	-4	-31	14	2	23	1	-14	40	23º 31' 00"	51º 13' 59"	-11	-13	-9	8	-13	-24	20	2	-10	-15	64
22º 41' 47"	51º 47' 23"	-20	-4	-11	28	-9	9	-19	3	-12	-12	46	23º 57' 00"	50º 01' 00"	-20	-4	-16	20	-10	-6	-5	-2	-1	-10	54
22º 47' 16"	51º 42' 41"	-14	0	-7	35	-24	14	2	-4	0	-24	21	23º 54' 14"	50º 34' 15"	-17	-17	0	18	-14	-10	-14	3	5	-10	55
22º 41' 59"	51º 38' 32"	-10	13	-9	23	-27	1	-17	-1	-2	-7	36	23º 12' 00"	49º 45' 00"	-27	1	-3	3	11	-5	7	10	3	-15	15
22º 43' 52"	52º 26' 47"	-11	-14	-8	25	-25	11	7	15	10	-28	18	23º 39' 00"	51º 21' 00"	-23	8	-16	18	-29	8	-1	6	8	-12	32
22º 58' 20"	50º 28' 44"	-9	8	-8	8	-32	9	-5	43	-9	-22	17	23º 24' 00"	51º 25' 59"	-22	-9	-7	-43	-31	15	4	36	2	11	44
22º 57' 55"	50º 15' 58"	1	19	-7	-1	-9	5	-19	12	0	-17	16	23º 46' 50"	50º 48' 51"	-27	13	-13	17	-12	-2	-25	3	8	-16	52
22º 45' 17"	51º 22' 26"	-26	-11	-16	23	-25	30	-15	16	-5	-23	51	23º 58' 59"	51º 04' 59"	-27	18	-15	10	-10	-8	-6	15	-11	-2	36
22º 56' 18"	53º 03' 03"	-22	-6	-13	17	-24	-3	-10	14	-10	18	39	24º 01' 02"	50º 41' 42"	-43	-30	-16	36	-8	-2	-9	15	4	-7	60
22º 49' 22"	51º 35' 44"	-24	-12	-15	11	-24	28	-2	10	-7	-16	52	24º 06' 00"	49º 28' 00"	-38	7	-1	-11	5	2	11	-15	18	-11	33
22º 58' 59"	50º 00' 00"	-14	6	-4	10	-25	8	-6	28	1	-11	6	24º 30' 39"	50º 24' 40"	-14	-12	11	5	-15	-12	-4	8	11	-25	47
22º 57' 00"	50º 37' 59"	-9	25	-17	14	-32	6	-14	19	1	-31	38	24º 12' 34"	50º 55' 28"	-1	34	-3	26	-24	-9	-13	9	-59	0	40
23ב 04' 59"	50ב 16' 59"	-5	-15	-1	51	-51	-2	-8	9	9	-29	42	24º 00' 26"	50º 08' 06"	-28	-30	-23	1	-10	13	4	20	2	-15	66
23º 03' 00"	51º 01' 59"	-23	-11	-27	17	-25	4	-11	20	15	-7	47	24º 04' 00"	49º 39' 00"	-23	8	-14	6	-7	-1	-11	-4	2	-4	48
23º 34' 59"	51º 04' 59"	-17	-6	-25	16	-17	0	-2	14	-8	-17	62	24º 51' 42"	50º 38' 55"	-39	14	14	20	2	-23	-9	-3	-16	-18	59
23º 02' 31"	50º 04' 12"	-34	1	-1	13	-12	-9	-3	22	8	-17	32	24º 29' 31"	50º 49' 07"	-14	22	-13	17	-16	-11	-8	19	-12	-16	32
23º 28' 40"	50º 56' 13"	-51	-13	-14	25	-33	-3	-2	19	11	-5	67	24º 58' 59"	50º 16' 00"	-10	20	-12	3	0	3	-19	-9	6	-23	41
23º 03' 58"	51º 15' 40"	-20	-5	-17	12	-11	0	19	-2	0	-2	27	24º 15' 31"	50º 05' 02"	-26	-24	-7	24	-2	-15	-12	22	-3	-7	51
23º 04' 48"	50º 45' 16"	-14	-4	-28	18	-10	12	-15	-4	27	-20	38	24º 22' 49"	50º 06' 32"	-28	16	18	21	-24	-2	-18	2	3	-17	31
23º 12' 26"	50º 47' 43"	-28	-10	-19	4	-22	-18	-4	19	43	-19	55	24º 45' 00"	50º 05' 21"	-6	31	6	8	-1	-12	-30	10	-8	-15	15
23º 15' 59"	50º 25' 55"	-21	-3	-10	2	-9	-9	-1	41	9	-17	19	24º 22' 59"	49º 34' 59"	-18	3	1	26	-10	6	-15	2	2	-13	15
23º 02' 25"	51º 48' 20"	-9	-24	-10	14	-20	20	-5	-2	-8	-11	53	24º 01' 55"	50º 41' 33"	-27	10	-16	2	-11	-12	-7	15	-2	-2	50
23º 26' 05"	50º 14' 43"	-22	-18	-8	32	-13	5	-10	20	15	-23	22	24º 57' 00"	50º 00' 00"	-9	27	-3	17	8	-2	-27	-10	1	-26	25
23º 37' 52"	50º 18' 35"	-16	-3	-16	28	-10	-15	-2	9	11	-10	24	24º 56' 15"	49º 49' 27"	-17	32	-6	7	-12	8	-12	1	1	-26	25
23º 18' 00"	50º 04' 00"	-28	-12	-15	14	6	-18	-29	10	24	-19	68	24º 39' 59"	50º 08' 04"	-27	1	4	17	3	-7	-12	7	9	-4	9
23º 51' 01"	50º 23' 28"	-29	-19	1	12	11	-3	-7	-3	-1	-7	46	24º 30' 01"	49º 43' 35"	-23	-7	-6	12	6	19	-5	-8	-3	-15	30
23º 38' 02"	50º 28' 28"	-7	-25	-20	12	3	-18	-10	47	21	-19	17	24º 31' 45"	49º 55' 44"	-32	18	12	21	-3	3	-18	2	6	-13	5
23º 23' 38"	50º 55' 26"	-34	7	-14	-4	-24	9	-18	25	14	-6	46	24º 37' 59"	49º 40' 59"	-20	-11	14	24	1	3	-21	-15	3	-12	34
23º 25' 00"	51º 57' 00"	-3	-3	-9	23	-34	3	7	-2	-7	-8	32	24º 40' 59"	50º 18' 00"	-33	14	-18	33	-3	-1	-17	2	8	-10	25
23º 45' 16"	49º 37' 21"	-19	-8	-15	39	-9	0	-4	11	8	-30	26	25º 14' 15"	50º 36' 02"	-20	-4	-4	-5	17	-9	-14	-11	20	-9	39
23º 54' 52"	49º 39' 00"	-24	-12	-7	-8	34	-8	14	-4	11	-35	38	25º 19' 00"	50º 00' 00"	-14	13	-1	14	-6	0	-32	13	-16	-21	50
23º 21' 00"	50º 37' 59"	-27	18	-17	15	-17	7	-7	11	-2	-2	20	25º 20' 29"	50º 47' 10"	-22	-1	0	9	10	4	-19	-8	6	-9	29
23º 14' 14"	51º 39' 41"	-12	-11	-29	-1	-24	27	-1	21	0	-13	43	25º 28' 30"	50º 17' 53"	-33	11	9	1	13	-18	-13	0	29	-25	27
23º 10' 59"	52º 10' 59"	-4	-11	-9	27	-30	26	0	21	-14	-21	16	25º 01' 59"	50º 46' 59"	-21	-4	2	10	13	-14	3	-11	7	-25	39
23º 24' 00"	51º 52' 26"	-18	-3	-35	17	-27	6	12	14	-12	-4	48	25º 29' 43"	50º 04' 35"	-20	-2	-7	-8	3	-16	-6	1	28	-26	52
23º 49' 00"	50º 07' 59"	-21	-5	-18	23	-16	-14	11	6	9	-20	44	25º 04' 32"	50º 23' 20"	-12	10	-8	-5	4	-7	-10	9	-5	-19	44
23º 31' 00"	50º 01' 59"	-28	-17	-8	19	-11	11	1	11	9	-17	29													

ext. dry	dry	normal	rainy	ext. rainy

Sources: Carmello (2013); Carmello et al. (2014); Carmello and Sant'Anna Neto (2014); Carmello and Sant'Anna Neto (2015)

3.2 Trend and variability of annual soybean production

Soy is the most important agricultural product of Paraná. All municipalities located in the study area are soybean producers. The agrarian structure data show that although many of the farms in these municipalities are small to medium in size, a small number of properties are extremely large. In general, the small farms have poorer access to modern crop practices and sophisticated technologies. In addition to this form of great disparity in the field, any significant variation in rainfall distribution exerts huge effects (decreases or increases) on the soybean yield, thereby affecting thousands of small landholders. There was no significant trend of increased soybean yield in most municipalities: increases occurred in only 17 (13%). These municipalities are mostly located in the northeastern portion of the study area, where there was a statistically significant trend of yield increase. However, other factors, such as greater agricultural investments in research, development and innovation aimed at agribusiness and grain production for export, also may have stimulated the increased yield (Fig. 6).

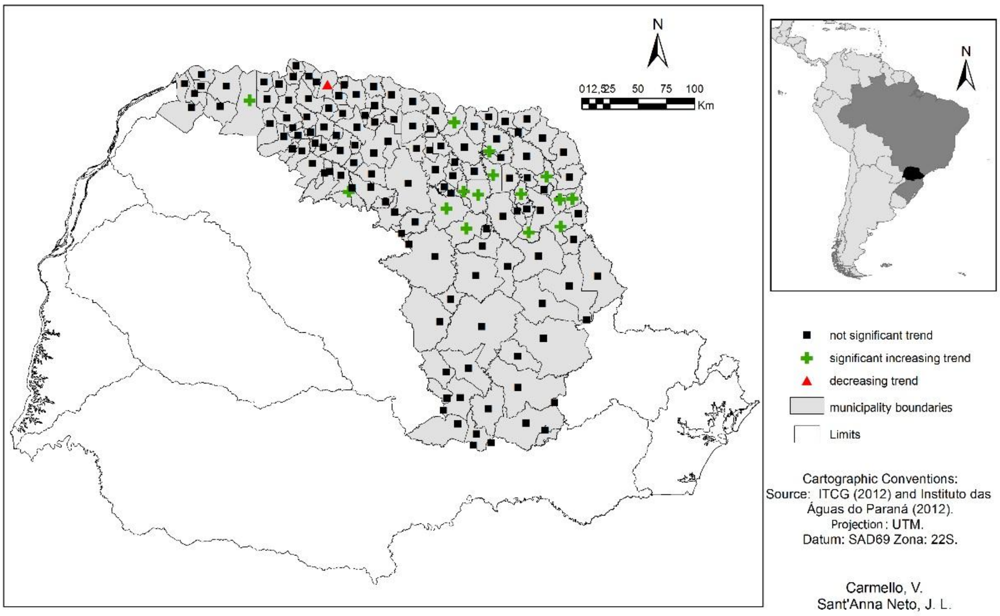

FIG. 6 MUNICIPALITIES WITH A POSITIVE TREND OF INCREASED YIELD DURING THE TEN YEARS OF STUDY: CARLÓPOLIS, CONGONHINHAS, CONSELHEIRO MAIRINK, IVAÍ, JOAQUIM TÁVORA, LEÓPOLIS, PINHALÃO, RIBEIRÃO DO PINHAL, SALTO DO ITARARÉ, SANTA AMÉLIA, SANTO ANTONIO DO PARAÍSO, SÃO JERÔNIMO DA SERRA, SAPOPEMA, SIQUEIRA CAMPOS, WENCESLAU BRAZ, JANDAIA DO SUL AND PARANAVAÍ

The average soybean yield in the 132 municipalities in the study area during the study period was 2,700 kg/ha. Depending on the agrarian structure, the size of the properties and degree of technological modernization, the soybean yield ranged from less than 1,500 k/ha to greater than 3,000 kg/ha. Regarding the annual yield variation between municipalities, the growing seasons of 1999-2000, 2003-2004, 2005-2006 and 2008-2009 had the highest variations in annual yield from one municipality to the next (Fig. 7). In these years, the yield in certain municipalities exceeded 3,000 kg/ha, which is excellent and is beneficial for the state, while the yield in others was below 1,500 kg/ha. Other years stand out for their low yield variations, particularly 2009-2010. The heights of the rectangles in Fig. 7 indicate these differences. The 2009-2010 season was one of low variation in the yields among the municipalities. The yields in most municipalities exceeded 2,700 kg/ha. The variation was low in the growing seasons of 2000-2001, 2002-2003, 2004-2005, 2006-2007 and 2007-2008. The 2004-2005 season showed the greatest variation in yield among the municipalities (the lowest median value) in addition to the lowest 75th percentile, indicating low yields in most municipalities compared to other years.

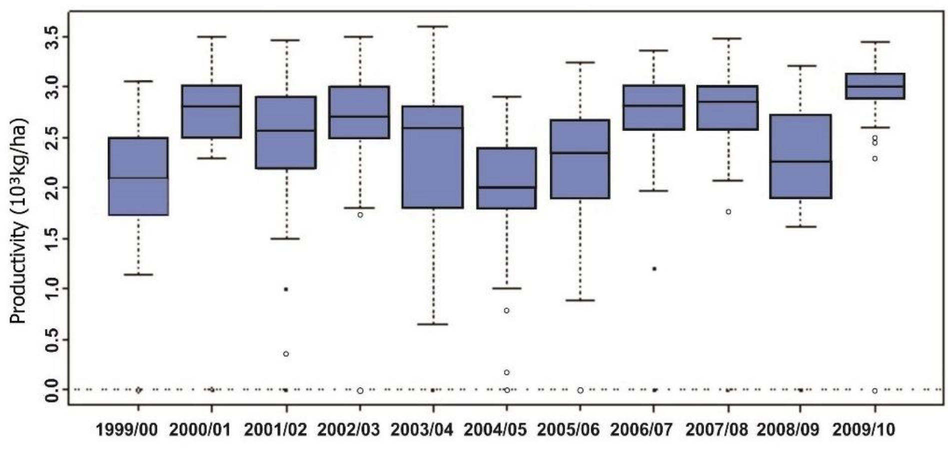

FIG. 7 VARIATION IN SOYBEAN YIELD AMONG THE MUNICIPALITIES LOCATED ON THE PARANÁ SLOPE OF THE PARANAPANEMA RIVER BASIN

3.3 Pearson's correlation

Correlation tests pertaining to the rainfall and yield data were conducted using the Kendall coefficient and applied to 62 municipalities (Table 4). The results were significant in 12 municipalities (Tab. 3). The highest dependence values were noted in Uraí (50%), Lupianópolis (52%), Castro (43%), Santa Amélia (34%) and Santo Antonio da Platina (34%).

TABLE 3
MUNICIPALITIES WITH STATISTICALLY SIGNIFICANT RESULTS

Municipalities	Kendall Coefficient correlation	Determination Kendall %	p-value
Cambara	0.514	26%	0.034
Castro	0.661	43%	0.006
Japira	0.574	33%	0.018
Leópolis	0.477	22%	0.050
Lupianópolis	0,722	52%	0.003
Ortigueira	0.496	24%	0.046
Ribeirão Claro	0.506	25%	0.044
Santa Amélia	0.587	34%	0.015
S. Antonio da Platina	0.587	34%	0.015
Sapopema	0.477	22%	0.050
Tibagi	0.648	42%	0.007
Uraí	0.709	50%	0.003

IV. CONCLUSION

We conclude that the historical rainfall series is homogeneous because of the low break results, although there is a marked increasing trend in the rainy season totals (October-April) exclusively at the rainfall stations located in the areas with a predominantly tropical climate (central and northern water basins). There were significant increasing trends in soybean yields in 15 (11%) of the municipalities. In general, there is a marked relationship between the analyzed variables, particularly in growing seasons of unusual rainfall: the extremely dry, dry, rainy and extremely rainy years. It was found that soybean yield among the municipalities is negatively correlated decreased total annual rainfall and positively correlated with rainfall when rainy periods occur. There was a significant correlation between the increased rainfall and increased yield. There was an increasing trend of both the annual rainfall and total soybean yield, particularly in the central and northern regions of the basin. There was no significant trend of increased soybean yield in most municipalities; increases occurred in only 17 of them (13%). This result is considered an indicator of what has been occurring in recent decades in Brazil and other countries in the developing world that are soybean producers, such as Argentina and India. These countries have become major commodity producers to support the constantly growing needs of consumers. The statistically significant correlations indicate that the soy dependence ranges from 22% to 50% in certain municipalities. Although the results indicate correlations, this type of dependence in Brazil has been decreasing, particularly in crops that are important for export. This is a consequence of the investments in science, technology and innovation in agribusiness, which is supported by the results indicating a trend of increasing yield in the municipalities of the northeastern basin. This pattern may be attributed to the current context of global markets, in which increases in income and decrease in costs and risks are basic requirements for competitiveness. To reduce yield losses caused by the annual rainfall variability, crops with different characteristics, such as drought-tolerant cultivars, and different types of crop management can be used (Farias et al. 2009; Battistti and Sentelhas 2015). However, this solution is not available to small and medium landowners, who do not have access to technological innovation due to either financial inability or lack of access to information. This situation occurs in regions with unequal peripheral capitalism, such as Brazil and its infrastructure-poor municipalities, including some examples in the state of Paraná.

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