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Mathematical equations representing the impacts of climatic factors on soybean productivity in the 2018/2019 crop season in the Parana State, Brazil

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ABSTRACT

In the 2018/19 crop season, throughout Parana State, water distribution was below that initially expected. In addition, air temperatures were above historical averages. Many soybean fields were affected in flowering and grain formation. As a consequence, there was a significant drop in crop productivity relative to the previous crop season of 2017/18. This work aimed to study the climatic and environmental variables that interfered with soybean productivity through mathematical regression models. Climate data from 19 INMET (2019) meteorological stations, distributed throughout Paraná, and soybean production, obtained from the Paraná Department of Agriculture, were used. Regression equations were generated using the linear, multiple linear, and stepwise regression methods, and making combinations of the independent variables (altitude, latitude, rainfall, and average air temperature) with the dependent variable being productivity. The equation that best represented the climatic and environmental conditions that occurred in the 2018/19 crop season in Parana was established by stepwise linear regression, involving altitude and latitude. The altitude presented a greater significance. Latitude showed less significance, being important, but not having the same importance as altitude in the soybean productivity process in the 2018/2019 crop season.

Introduction

Plant survival is directly dependent on the relationships among the soil-plant-atmosphere system, where water is the most important factor, and on which the survival of these plants depend on. Low or insufficient rainfall distribution throughout the crop season is considered the main cause of the limitations of field crops (Faria et al. 1993). According to Farias et al. (2007), the air temperature, photoperiod, and rainfall distribution are the most important climatic factors for soybean crops, and according to those same authors, in general, that crop adapts well over a temperature range between 20 and 30 °C. Besides, Bergamin et al. (1999) had previously stated that soybean plants adapt well in regions where the mean rainfall during the crop season is situated between 700 mm to 1200 mm.

In studies carried out in Londrina, Paraná, it was found that the highest soybean yields were obtained within the rainfall range between 650 mm to 700 mm, and which were well distributed throughout all the crop cycle (Farias et al. 2007). However, Zanon et al. (2018) stated that throughout the developmental cycle of a crop with high productivity potential requires at least 800 mm of rainfall. These results demonstrate that there is an optimal range of water and temperature distribution during all the crop cycle for the plants to be able to express all their productive potential.

However, water participates in a cycle in which local environmental conditions, such as the soil water storage capacity, vegetation cover, and ambient temperature greatly influence the conditions of water availability for plants. Water losses due to the soil water evaporation, and transpiration of plants, gave rise to the term evapotranspiration, which was created by Wilm et al. (1944) to explain the combination of the direct evaporation of water from a soil surface and the transpiration of plants, emphasizing that on a vegetated surface these two processes occur simultaneously. Moreover, according to Pereira et al. (2002), the evapotranspiration is controlled by the availability of energy, the atmospheric demand, and the supply of water available to the plant. The availability of energy depends on the geographic location (mainly latitude and altitude) and the season of the year. Altitude is also important due to the great influence on air and soil temperatures, and atmospheric pressure; which are important factors for evapotranspiration.

The state of Paraná is situated in a transition region between the temperate and tropical climates; and as a result, it presents great variability, both in thermal and hydric terms. Soybean is grown in the spring-summer period, and under different edaphoclimatic conditions. In this period, rainfall distribution is generally sufficient to meet the needs of the soybean crop across the state. In addition, the crop is grown in areas ranging between 200 m to 1100 m in altitude, which imposes a wide range of temperatures during the day as well as at night. Besides, in the summer, irregularities in the rain distribution may occur, with alternation between very rainy periods and very dry periods. Such climatic variations can cause damage to several crops, including soybean; with possibilities of water deficiency during the critical development periods of the plants, such as on the phenological stage of flowering, as well as the grain development phase. Concerning that, Zanon et al. (2018) stated that temperatures in the range of 25 °C during the soybean reproductive period provide optimal conditions for the plants to express their best productivity potential, and those productivities may be compared to the best productivities obtained of the higher altitude crop regions of the Rio Grande do Sul State.

However, in the 2018/2019 crop season, in all of Paraná State, the rain distribution was far below the mean previously expected (mainly in the west, northwest, and north regions), and as an aggravating factor, temperatures were well above historical means. Such a dry and hot scenario persisted from November 2018 to February and March 2019, when many soybean fields in the Paraná State were at the most critical moment of their development, i.e., flowering and/or grain formation stages (Gonçalves & Foloni 2019). That severe drought has resulted in a significant drop in productivity in several regions of the state (Paraná 2019), and according to the same source, soybean production in the Parana state was reduced by 3 million metric tons, compared to the crop season of 2017/2018.

Given the above, this research work aimed at studying the climatic and environmental variables responsible for the severe drop on soybean productivity through mathematical regression models; thus allowing us to graphically visualize and understand the productivity obtained in each soybean-producing region of the Parana State in the crop season of 2018/2019.

Material and Methods

Research Data

Information from the climatological data series of 19 INMET (2019) automatic meteorological stations, distributed throughout the Paraná State, was used (Table 1). Data on the mean air temperatures and rainfall distribution of each meteorological station were obtained for the most critical period in the 2018/2019 crop season; which lasted from the first 10 days of November 2018 until the first 10 days of February 2019, which was the period when water deficiency was most significant in the state.

Statistical Methods

b.1) Univariate Analysis

Linear regression models, multiple linear regression, and stepwise regression were applied to climatological data with the following variables: final productivity (kg ha^{-1}); rainfall (mm); altitude (m); latitude (°); and mean air temperature (°C) all collected at each location studied. It is worth emphasizing herein that the regression analysis method stands out in climatology studies for mapping or spatializing data (Draper & Smith 1998).

Data on productivity (Table 1) were obtained from the Paraná Department of Agriculture, in its annual harvest forecast survey accomplished by the Rural Economy Department (DERAL) (Paraná 2019). These data were

Table 1. Municipalities, latitude, altitude, mean air temperatures, and rainfall amounts provided by the INMET meteorological stations located in the Paraná State from November 10, 2018, to February 10, 2019, as well as data on regional soybean productivity, provided by SEAB/DERAL after the 2018/2019 crop season.

Municipality	Latitude (S)	Altitude (m)	Mean air temp. (° C)	Rainfall (mm)	Regional productivity (kg ha^{-1})
Campina da Lagoa	24.57	598	25.41	500	2778
Castro	24.78	994	20.98	430	3600
Cidade Gaúcha	23.35	366	26.13	526	2170
Clevelândia	26.41	966	23.82	538	3327
Dois Vizinhos	25.69	546	23.89	395	3130
Foz do Iguaçu	25.60	225	25.59	437	2126
General Carneiro	26.39	1009	20.18	535	3366
Icaraíma	23.39	381	26.29	286	2170
Inácio Martins	25.56	1209	19.46	494	3557
Japira	23.77	593	23.74	405	2675
Joaquim Távora	23.50	513	24.70	397	2675
Laranjeiras do Sul	25.36	835	23.68	535	3130
Marechal C. Rondon	24.53	392	25.41	268	2126
Maringá	23.40	549	25.74	402	2601
Nova Fátima	23.41	664	25.26	245	2675
Nova Tebas	24.43	656	25.1	369	2909
Paranapanema	22.65	309	26.63	249	2100
Planalto	25.72	399	24.98	416	3130
Ventania	24.28	1093	21.09	411	3600

Sources: INMET (2019) and Paraná (2019).

obtained by the regional nuclei, and it was assumed that the corresponding productivity for the municipalities with INMET (2019) meteorological stations would be obtained by the nearest regional nucleus. Regression analyzes for this study were performed using the software SAS - Statistical Analysis System, version 9.4 (SAS 2016), and graphs were built using the software Statistica (Statsoft 2007).

Linear Regression

Several quantitative statistics are indicated for the appropriate selection of models such as the determination coefficient , adjusted determination coefficient, residual means square (RMS), and the Mallows statistic (Cp), as well as some graphs explaining the adjustment of models. To obtain these statistics, it was necessary to use well-known linear models (Draper & Smith 1998). Thus, linear regression analyzes were initially performed between productivity (response or dependent variable) and other climatic and environmental variables, one by one, called explanatory or independent variables which were expressed by the following model:

$$Y= \alpha+\beta x+ \varepsilon$$

in which:

α nd β are the parameters to be estimated with the data;

is the independent variable with zero correlation; and

ε represents the effect of random error.

Multiple Linear Regression

Similarly, to evaluate the contribution of more than one independent variable in the model associated with the productivity variable, which allows a better explanation of the climatic and environmental effects on productivity, the multiple mathematical statistical model was used as follows:

$$Y= \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_k x_k + \varepsilon$$

in which:

$\beta_1, \beta_2, ..., \beta_k$ are the parameters to be estimated with the data;

$x_1, x_2, ..., x_k$ are independent variables with null correlation; and

ε represents the effect of random error.

Stepwise Linear Regression (step by step)

This procedure uses all the independent variables in the model and where, according to a given level of significance, each variable enters and leaves the model, but considers only the highest determination coefficient as a selection criterion, meaning that such a model will be the same one utilized in the Multiple Linear Regression item.

b.2) Multivariate analysis – Principal Components Analysis

A requirement in Principal Component Analysis (PCA) and subsequent use of the polygonal biplot graph that allows to simultaneously interpret the effects of the variables and treatments is that at least Pearson's correlation coefficients between the variables were equal or greater than r = 0.30 (Yan & Tinker 2006; Figueiredo Filho & Silva Júnior 2009; Hongyu et al. 2015). In addition, the correlation between all variables was performed to better explain the effects of factors that interfered with the productivity of the crop.

Results and discussion

All regression equations were generated by the following methods: linear regression, multiple linear regression, and stepwise regression, while performing different combinations of the independent variables (altitude, latitude, rain, and mean air temperature) with productivity, which is the dependent variable. Then data were evaluated as to the ability to estimate productivity for each location by comparing them with the productivity data actually obtained. The parameters obtained with the linear, multiple linear, and stepwise regression models are shown in Table 2.

After the linear regression analysis, it was observed that equations 2 and 4 allowed better adjustments of the significant determination coefficients for the regression among the productivity, altitude, and temperature variables; and also allowed verifying that the highest productivities were obtained on soybean crop fields grown on higher altitude locations (Table 2; Figures 1 and 2).

All multiple regressions with two, three, or four independent variables, excepting equation 11, showed significant coefficients of determination, but they were not very explanatory. However, equation 10, with the variables latitude and altitude, was the most efficient, with an adjusted of 0.82; thus allowing a better interpretation of the environmental and climatic phenomena involved, which coincided with the stepwise regression with two steps (Table 2).

Equations 14 and 15, resulting from stepwise regression, indicated that in step 1, the altitude presented greater significance (F = 64.44 and Pr (F) = <0.0001) (Table 3) and the latitude (F = 5.08 and Pr (F) = 0.038) (Table 3), in its turn, showed less significance on the soybean productivity in the 2018/2019 crop season. However, when both variables latitude and altitude were considered together in the model, there was a greater contribution of the altitude; which also showed a higher coefficient of determination.

It was evident that soybean production in the 2018/2019 crop season was higher in locations with milder air temperatures (Figure 2). In the regressions involving the productivity and rainfall of the variable, the coefficients of determination were low and not significant (Table 2).

At the end of the computations of all equation models utilized involving multiple linear regression (Equations from 1 to 13) and stepwise regression, the stepwise regression model with two steps was the one that showed

Table 2. Linear, multiple linear, and stepwise regression equations; as well as values of the determination coefficient, adjusted determination coefficient, and significance information, obtained from data collected in Paraná State, in the 2018/2019 crop season.

Simple Linear Regression Equation	**R^2**	**$R^2_{Adjusted}$**	**Significant Parameters**
Ŷ1 = -4042.7199 + 279.9046 * Lat	0.36	0.32	Lat
Ŷ2 = 1783.2591 + 1.6234 *Alt	0.79	0.78	Intercept and Alt
Ŷ3 = 1681.5915 + 2.7924 * Rain	0.26	0.21	Intercept and Rain
Ŷ4= 7885.4581 – 209.5238 * Temp	0.72	0.71	Intercept and Temp
Multiple Linear Regression Equation	**R^2**	**$R^2_{Adjusted}$**	**Significant Parameters**
Ŷ5= -26.674 + 112.132 * Lat + 1.258 * Alt – 0.097 * Rain - 27.72 * Temp	0.84	0.80	Alt
Ŷ6= -1050.3138 + 122.6061 * Lat + 1.4284 * Alt - 0.1270 * Rain	0.84	0.81	Alt
Ŷ7= 65.3576 + 107.7291 * Lat + 1.2462 * Alt - 28.3981 * Temp	0.84	0.81	Alt
Ŷ8= 3404.345 + 1.120 * Alt + 0.539 * Rain -62.977 * Temp	0.85	0.70	Intercept and Temp
Ŷ9= 5002.7021 + 91.6542 * Lat - 183.3514 * Temp	0.75	0.72	Intercept and Temp
Ŷ10= -962.7297 + 117.1851 * Lat +1.4179 * Alt	0.84	0.82	Lat and Alt
Ŷ11= -2962.0226 + 215.0427 * Lat +1.2427 * Rain	0.39	0.39	NS
Ŷ12= 1591.47 + 1.5260 * Alt + 0.6175 * Rain	0.80	0.78	Intercept and Alt
Ŷ13= 3720.324 + 1.1712 * Alt – 68.206 * Temp	0.81	0.78	Intercept and Alt
Stepwise Linear Regression Equation in Step 1 and 2	**R^2**	**C_p**	**Significant Parameters**
Ŷ14= 1783.2591 + 1.6234 *Altitude (step 1)	0.79	3.74	Intercept and Alt
Ŷ15= -962.7297 + 117.1851 * Latitude +1.4179 * Altitude (step 2)	0.84	1.22	Lat and Alt

Ŷ1, ... Ŷn = Dependent Variable Productivity in kg ha^{-1}; R^2 = Coefficient of Determination; $R_{Adjusted}^2$ = Adjusted coefficient of Determination; C(p) = C(p) of Mallows. Temp = Mean air temperature; Alt = Altitude; Lat = Latitude.

Figure 1. Linear regression graph between altitude and soybean productivity obtained regionally in the state of Paraná, in the 2018/2019 crop season (equation 2, Table 2).

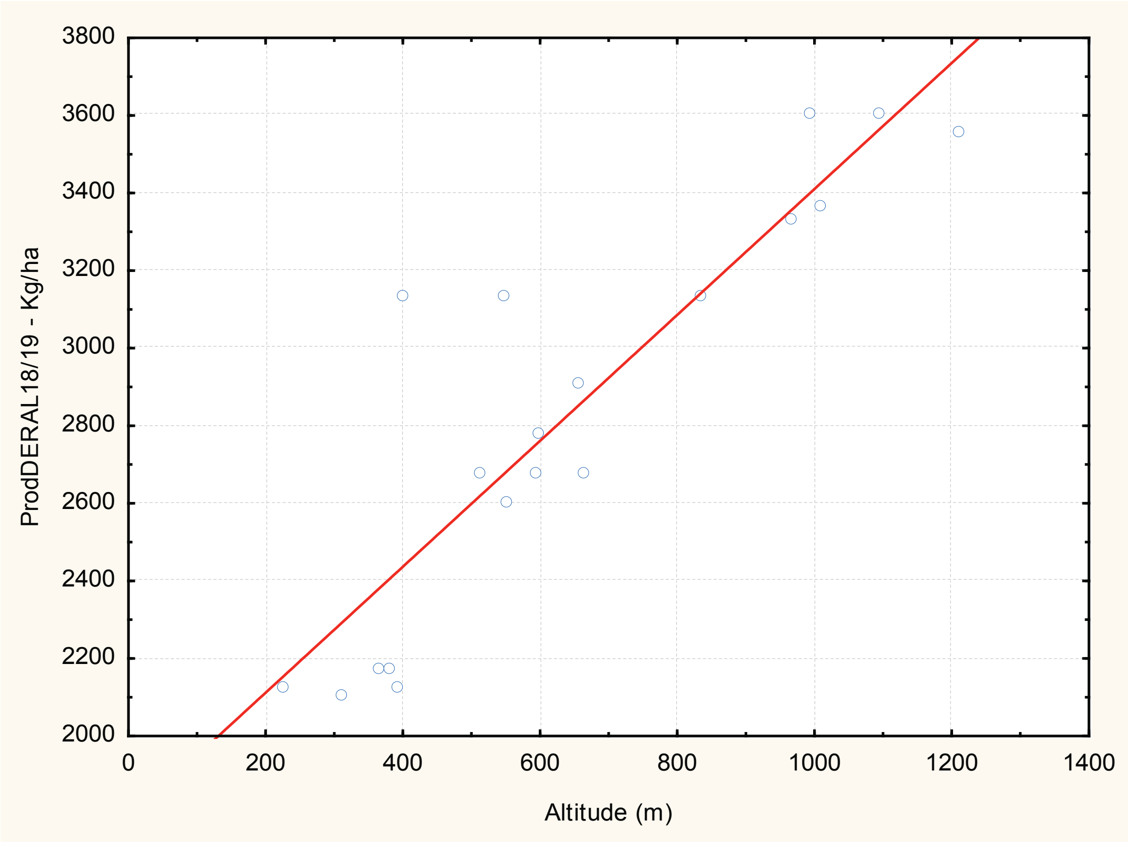


Figure 2. Relationships between regional soybean productivity and mean temperatures, computed with data collected at several locations in Paraná State, in the 2018/2019 crop season.

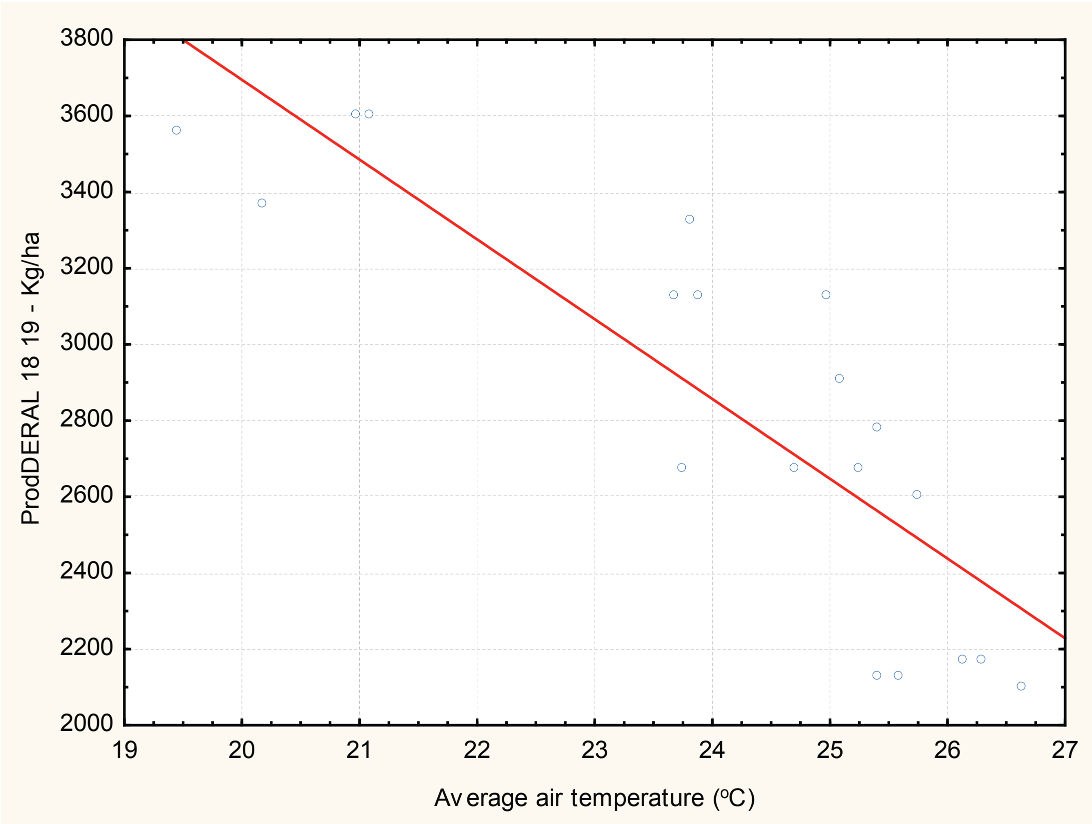


Table 3. Values of Residual Mean Squares, values of F, and probabilities of F

Linear Regression Equation	Residual Mean Square	F Value	Pr(F)
1- Productivity × Latitude	190,173.16	9.54	0.0067
2- Productivity × Altitude	61,971.39	64.44	<0.0001
3- Productivity × Rain	219,964.56	5.95	0.0260
4- Productivity × Mean Temp.	81,889.57	44.63	<0.0001
Multiple Linear Regression Equation	**Residual Mean Square**	**F Value**	**Pr(F)**
5- Productivity × Latitude × Altitude × Mean Temp. × Rain	56,201.43	18.95	<0.0001
6- Productivity × Latitude × Altitude × Rain	53,197.95	26.62	<0.0001
7- Productivity × Latitude × Altitude × Mean Temp.	52,515.72	27.04	<0.0001
8- Productivity × Altitude × Rain × Mean Temp.	62,576.00	21.89	<0.0001
9- Productivity × Latitude × Rain × Mean Temp.	82,713.00	15.34	<0.0001
10- Productivity × Latitude × Mean Temp.	78,414.53	24.18	<0.0001
11- Productivity × Latitude × Altitude	49,970.17	42.50	<0.0001
12- Productivity × Latitude × Rain	191,960.83	5.15	<0.0188
13- Productivity × Altitude × Rain	62,746.00	32.22	<0.0001
14- Productivity × Altitude × Mean Temp.	60,998.61	33.37	<0.0001
Stepwise Linear Regression Equation	**Residual Mean Square**	**F Value**	**Pr(F)**
15- Productivity × Altitude	61,971.39	64.44	<0.0001
16- Productivity × Altitude × Latitude	53,197.95	26.62	<0.0001

the best ability to estimate productivity, and it was also the one showing the best approach for data obtained in the 2018/2019 crop season (Equation 15; Table 2). The differences between the measured productivities and the statistically estimated productivities are shown in Table 4.

Moreover, when applying linear regression under three different situations relating the variables one by one to productivity, the most significant regressions with the coefficient of determination (R^2) were those that involved the variables altitude and mean temperature (Table 2).

Concerning multiple regressions, relating productivity with four, three, or two variables, in most cases the variable that best fitted to data was the altitude (six times), followed by the temperature (two times), and only in one time to the variables latitude and altitude together (Table 2).

When the regression analyses were performed among all independent variables and productivity by using the stepwise method, it was possible to visualize the contribution of the most important variables within this study: altitude and latitude; which were the variables providing the highest value for the coefficient of determination ($R^2 = 0.84$). As can be observed in Table 2, the Cp Mallows statistic in the stepwise analysis (equations 14 and 15) was reduced when associated with the altitude and latitude variables, once it was associated with the second-lowest Residual Mean Square found within this study (RMS = 53,197.95). The F statistic for the altitude variable was very significant as compared to the F value of latitude. It is also observed that in the regression equations for which the (R^2) was low, the F statistic decreased; thus, increasing the value of the Residual Mean Square (Tables 2 and 3).

In the multiple linear regression, there was the presence of high values for Residual Mean Squares, with significant F values due to the importance of the altitude variable. At Clevelândia and General Carneiro, the altitude and latitude variables showed the highest values, even when situated within the range of low mean temperatures (Tables 1 and 2; Figure 3).

Table 4 shows the best-fitted model (Equation 15; Table 2) demonstrating a relatively good ability to predict productivity in the 2018/2019 crop season. Nevertheless, for some locations, the estimated errors were higher than in the others (Mean productivity × Estimated productivity). The equation clearly represented the effects of the variables altitude and latitude; thus evidencing the variability on productivity as a function of the geographic conditions of the locality where a given production level was achieved.

Additionally, in this study, correlations among all variables were made, and it was desirable that the coefficients were equal or greater than 0.30, which was satisfactorily met. The correlation coefficients ranged from r = - 0.47 to r = 0.89, and the best relationships were between productivity × altitude, altitude × mean temperature, and productivity × mean temperature (Table 5).

Considering original data (Table 1), the locations presenting the best productivities were those municipalities with higher altitude and latitude, which were associated with mild temperatures and an adequate amount of rainfall to guarantee such productivities. This is demonstrated at the vertices of the polygonal biplot graph, where on the right side are concentrated the municipalities

Table 4. Municipalities, latitude, and altitude of INMET meteorological stations located in Paraná State; regional soybean productivity (SEAB / DERAL) in the 2018/2019 crop season; and productivity estimated by the equations among productivity, altitude, and latitude.

Municipality	Latitude (S)	Altitude (m)	Regional Mean productivity (kg ha^{-1})	Estimated productivity (kg ha^{-1})
Campina da Lagoa	24.57	598	2778	2764
Castro	24.78	994	3600	3350
Cidade Gaúcha	23.35	366	2170	2292
Clevelândia	26.41	966	3327	3501
Dois Vizinhos	25.69	546	3130	2822
Foz do Iguaçu	25.60	225	2126	2356
General Carneiro	26.39	1009	3366	3560
Icaraíma	23.39	381	2170	2318
Inácio Martins	25.56	1209	3557	3746
Japira	23.77	593	2675	2663
Joaquim Távora	23.50	513	2675	2518
Laranjeiras do Sul	25.36	835	3130	3193
Marechal C. Rondon	24.53	392	2126	2467
Maringá	23.4	549	2601	2557
Nova Fátima	23.41	664	2675	2722
Nova Tebas	24.43	656	2909	2830
Paranapoema	22.65	309	2100	2129
Planalto	25.72	399	3130	2617
Ventania	24.28	1093	3600	3432

Table 5. Pearson's correlation coefficients.

	Latitude	Altitude	Rain	Mean air Temp.	Productivity
Latitude	1.00	0.45	0.61*	-0.54	0.60
Altitude		1.00	0.47	-0.89	0.89
Rainfall			1.00	-0.47	0.51
Mean air Temp.				1.00	-0.85
Productivity					1.00

* Figures written in red are significant for p <0.05, and N = 19.

of Ventania, Castro, Inácio Martins, General Carneiro, and Clevelândia; which were the localities presenting the best productivities (Figure 3). Contrarily, according to Yan and Tinker (2006), results plotted at the left side of a polygonal biplot graph, are not always good, and may be extreme; i.e., sometimes they may be very poor or otherwise very good. In the present case, the municipality of Paranapoema stood out negatively, for presenting the lowest altitude, the highest mean temperatures, and consequently the lowest values for productivity.

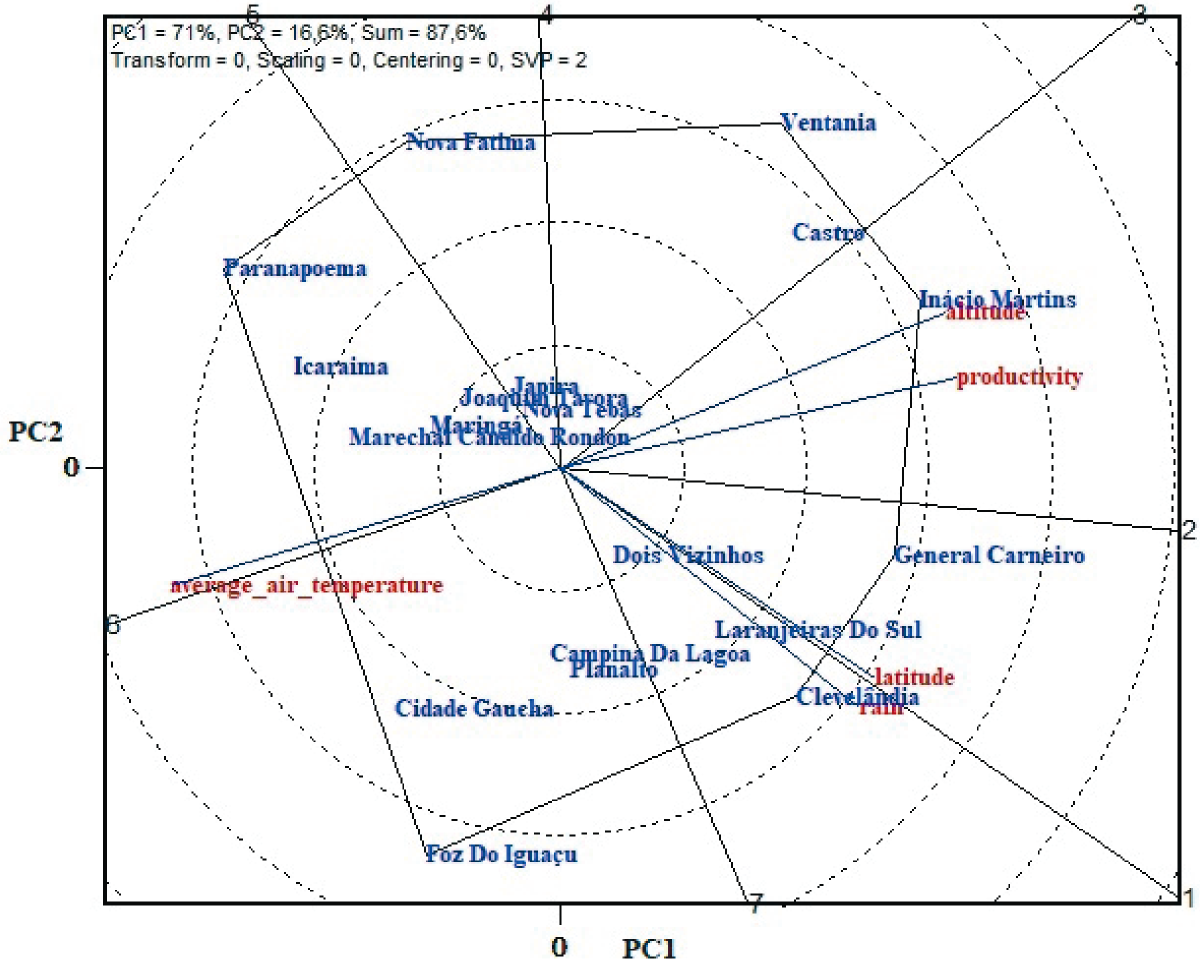
Normally, the characteristics plotted close to the origin of a polygonal biplot graph have a low contribution. Thus, the locations or variables presenting the longest vectors are the best or the worst. Although in this research work the locations of the variables were plotted at the apex of the polygon does not always indicate the best response. Nevertheless, according to Yan and Tinker (2006), although the treatments are located on the left side of the polygonal biplot graph, they may indicate the worst values and may be misinterpreted (Figure 3).

After all the data were processed, it was possible to assemble a table with all the locations where data on the variables studied were collected (Table 6).

The adjusted mathematical equations within this study were performed in the sequence being each one checked concerning its correct application, and the one best that represented the climatic and environmental conditions occurring during the soybean crop season of 2018/2019 in Paraná State was equation 15 (Table 2) performed using the stepwise linear regression, for which estimated data are shown on Table 4.

In general, during the soybean growing season of 2018/2019, in all the Paraná state, there was a high reduction on the rainfall distribution linked to a significant increase on diurnal and nocturnal temperatures (Gonçalves 2019); and according to the same author, the most critical period during the crop season throughout the state occurred in December 2018, with rainfall amount reductions ranging from 28% to 64%, depending on the region. Such a reduction in rainfall distribution was greater at the lower altitude of the west, northwest, and north regions. Moreover, temperatures ranged 2 to 3 °C above historical means; thus, in those regions, the productivities declined 13% to 37%, relative to the previous crop season (Paraná 2019). However, in the south of the Paraná state, where

Figure 3. Polygonal biplot between the two main components between locations and response variables altitude, latitude, rain, average temperature, associated with soybean productivity in Paraná Harvest: 2018/2019. PC1 = 71% and PC2 = 16.6%, totaling 87.6% of the total variation.



soybean is grown on crop fields with higher altitudes, the drop on rainfall occurrence was only 8%. Therefore, under milder temperatures, the productivity was higher, with only a 3% drop as compared to the previous crop season (Paraná 2019).

For the reasons described before, the crop season of 2018/2019 may be considered atypical, for the environmental factors had a major influence on productivity (Figure 2). Therefore, considering the climatic conditions of the highest locations, there were losses of humidity due to the atmosphere being lower than in the lower locations, thus providing better conditions for fairly normal productivity, which did not occur on the cultivation fields located at lower altitudes.

These results are presented in the graph plotted in Figure 1, where it can be observed that the reduction in soybean production in Paraná State was highly significant since it occurred in the western and the northern regions, in which on normal crop years the farmers obtain very good yields. Conversely, in the 2018/2019 crop season, in addition to receiving lesser amounts of rainfall, those regions also had temperatures above the historical means (Figure 2); which contributed to the high water losses due to evapotranspiration with a consequent drop on productivity.

Conclusions

These results show that, in the Paraná State, in an atypical crop season such as that of 2018/2019, an environmental factor such as the altitude was very important for soybean productivity, which is an effect that in a normal year would be less noticeable (Table 1; Figures 1 and 3). In turn, the latitude was less significant but also had its impact. The northwest region, with lower altitude and latitude, and where the soils are sandy, presented the lowest productivity levels and was the region with the highest temperatures resulting in the lowest productivity; which was largely due to the high water losses as a consequence of high evapotranspiration.

Table 6. Data on the variables: latitude; altitude; rainfall; and mean temperature collected at several municipalities of Paraná State during the soybean crop season of 2018/2019, and statistically organized in descending order for each location.

Location	Lat	Location 1	Alt	Location 2	Rainfall	Location 3	Mean. Temp.	Location 4	Productivity kg ha^{-1}
Clevelândia	26.41	Inácio Martins	1209	Clevelândia	538	Paranapoema	26.63	Ventania	3600
General Carneiro	26.39	Ventania	1093	Laranjeiras do Sul	535.2	Icaraíma	26.29	Castro	3600
Planalto	25.72	General Carneiro	1009	General Carneiro	534.6	Cidade Gaúcha	26.13	Inácio Martins	3557
Dois Vizinhos	25.69	Castro	994	Cidade Gaúcha	526	Maringá	25.74	General Carneiro	3366
Foz do Iguaçu	25.6	Clevelândia	966	Campina Lagoa	500.4	Foz do Iguaçu	25.59	Clevelândia	3327
Inácio Martins	25.56	Laranjeiras do Sul	835	Inácio Martins	494	Campina Lagoa	25.41	Laranjeiras do Sul	3130
Laranjeiras do Sul	25.36	Nova Fátima	664	Foz do Iguaçu	437	Marechal Rondon	25.41	Dois Vizinhos	3130
Castro	24.78	Nova Tebas	656	Castro	430.8	Nova Fátima	25.26	Planalto	3130
Campina Lagoa	24.57	Campina da Lagoa	598	Planalto	416	Nova Tebas	25.1	Nova Tebas	2909
Marechal Rondon	24.53	Japira	593	Ventania	411	Planalto	24.98	Campina Lagoa	2778
Nova Tebas	24.43	Maringá	549	Japira	405	Joaquim Távora	24.7	Nova Fátima	2675
Ventania	24.28	Dois Vizinhos	546	Maringá	402.2	Dois Vizinhos	23.89	Japira	2675
Japira	23.77	Joaquim Távora	513	Joaquim Távora	397	Clevelândia	23.82	Joaquim Távora	2675
Joaquim Távora	23.5	Planalto	399	Dois Vizinhos	394.8	Japira	23.74	Maringá	2601
Nova Fátima	23.41	Marechal. Rondon	392	Nova Tebas	369.4	Laranjeiras do Sul	23.68	Icaraíma	2170
Maringá	23.4	Icaraíma	381	Icaraíma	286	Ventania	21.09	Cidade Gaúcha	2170
Icaraíma	23.39	Cidade Gaúcha	366	Marechal Rondon	268.4	Castro	20.98	Marechal Rondon	2126
Cidade Gaúcha	23.35	Paranapoema	309	Paranapoema	249.2	General Carneiro	20.18	Foz do Iguaçu	2126
Paranapoema	22.65	Foz do Iguaçu	225	Nova Fátima	245.8	Inácio Martins	19.46	Paranapoema	2100

Source: INMET (2019) and PARANÁ (2019

Author contributions

S. L. GONÇALVES, M.C.N. OLIVEIRA, J. R. B. FARIAS, and R. N. R. SIBALDELLI designed the study, performed the analysis and wrote the paper.

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Equações matemáticas representando os impactos dos fatores climáticos na produtividade da soja na safra 2018/2019 no Estado do Paraná, Brasil

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RESUMO

Na safra agrícola de 2018/19, em todo o Paraná, a distribuição hídrica ficou abaixo daquela inicialmente esperada. Além disso, as temperaturas foram superiores às médias históricas. Muitas lavouras de soja foram atingidas no florescimento e formação dos grãos. Como consequência houve uma sensível queda de produtividade da cultura com relação à safra anterior, de 2017/18. O objetivo deste trabalho foi o estudo das variáveis climáticas e ambientais que interferiram na produtividade, por meio de modelos matemáticos de regressão. Foram utilizados dados de clima de 19 estações meteorológicas do INMET (2019), distribuídas pelo Paraná e de produtividade da soja, obtidos junto à Secretaria de Agricultura do Paraná. Foram geradas equações de regressão pelos métodos de regressão linear, linear múltipla e *stepwise*, fazendo-se combinações das variáveis independentes (altitude, latitude, chuva e temperatura média) com a variável dependente, produtividade. A equação que melhor representou as condições climáticas e ambientais ocorridas na safra 2018/19, no Paraná, foi estabelecida por regressão linear *stepwise*, envolvendo altitude e latitude. A altitude apresentou uma significância maior. A latitude demonstrou significância menor, sendo importante, porém não tendo a mesma importância que a altitude no processo da produtividade na safra 2018/2019.

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