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Influence of meteorological variables and geographic factors in the selection of soybean lines

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ABSTRACT

This study aimed to evaluate the influence of meteorological variables and geographic factors on the selection of soybean lines concerning grain yield in Brazil and Paraguay soybean-producing regions. The study was conducted in seven different environments: Bela Vista do Norte - PY, Palotina - PR, Mangueirinha - PR, Major Vieira - SC, Três Passos - RS, Toledo – PR, and Passo Fundo - RS. The randomized block design in an incomplete factorial scheme with six soybean genotypes (G1, G2, G3, G4, G5, and G6) was used for the experiments. The harvest occurred in the first half of March, and grain yield was measured through the total harvest of the plot and expressed in kg ha^{-1}, with grain moisture at 13%. The climatic variables used in the study were maximum air temperature (Tmax, ºC), average air temperature (Tavg, ºC), minimum air temperature (Tmin, ºC), relative air humidity (RH, %), precipitation (Prec, mm), wind speed (WS, m/s), dew point (DP, °C), incident radiation (Rad_Inc, MJ/m²), and total radiation (RAD_OL, MJ/m²); and geographic factors were altitude (ALT), longitude (LON), and latitude (LAT). The G5 genotype with a genetic value for grain yield above the general average is the most adapted to favorable environments. Altitude had the greatest influence on the biological variability of the genotypes, with a negative correlation of moderate magnitude with grain yield. Grain yield was enhanced in environments with altitudes lower than 338 m at latitudes below 24.17S.

Keywords: *Glycine max*, Reaction norm, Linear correlation, Multiple regression.

Influência de variáveis meteorológicas e fatores geográficos na seleção de linhagens de soja

RESUMO

Este trabalho teve como objetivo avaliar a influência de variáveis meteorológicas e fatores geográficos na seleção de linhagens de soja em relação à produtividade de grãos em regiões de soja do Brasil e Paraguai. O estudo foi realizado em sete ambientes distintos: Bela Vista do Norte – PY, Palotina – PR, Mangueirinha – PR, Major Vieira – SC, Três Passos – RS, Toledo - PR e Passo Fundo - RS. O delineamento experimental utilizou blocos casualizados em esquema fatorial incompleto, utilizando seis genótipos de soja (G1, G2, G3, G4, G5 e G6). Na colheita da primeira quinzena de março, a produtividade de grãos foi medida através da colheita total da parcela e expressa em kg ha^{-1}, com umidade de grãos em 13%. As variáveis meteorológicas utilizadas no presente estudo foram: temperatura máxima do ar (Tmax, ºC), temperatura média do ar (Tavg, ºC), temperatura mínima do ar (Tmin, ºC), umidade relativa (RH, %), precipitação (Prec, mm), velocidade do vento (WS, m/s), ponto de orvalho (DP, °C), radiação incidente (Rad_Inc, MJ/m²) e radiação total (RAD_OL, MJ/m²). O genótipo G5 com valor genético para produtividade de grãos acima da média geral é o mais adaptado a ambientes favoráveis. A altitude exerceu a maior influência na variabilidade biológica dos genótipos, com correlação negativa de magnitude moderada com a produtividade de grãos. A produtividade de grãos foi potencializada em ambientes com altitude inferior a 338 m em latitudes abaixo de 24.17S.

Palavras-chave: *Glycine max*, Norma de reação, Correlação linear, Regressão múltipla.

1. Introduction

Soybean (*Glycine max* L.) is one of the most cultivated species in the world due to its great agricultural, social, economic, and nutritional importance (Gazzoni, 2018). Brazil is the world's largest producer of this oilseed, which in 2021 produced 134,9 million tons, followed by the United States with 120,7 million and Argentina with 46,2 million (FAO, 2021). Brazilian production is estimated to reach 153,64 million tons of grain, with a grain yield of 3.520 kg ha^{-1} in an area of 43.5 million hectares in the 2022/2023 crop season.

Although the area of cultivation and production takes place on a large scale, some future and current challenges concern society. According to ONU (2019), the population tends to reach 9.7 billion people in 2050 and associated with this, there are concerns about food security. Meeting new demands for food will be one of the main challenges in the future (Saath and Fachinello, 2018). One of the alternatives to meet this need is animal and plant breeding.

The purpose of plant breeding is to develop superior genetic constitutions, as well as the selection and positioning of genotypes for more efficient and sustainable management. In addition, they result in higher yields, reduced production costs, and lower negative effects on the cultivation environment (Carvalho et al., 2002).

Therefore, we can mention some abiotic factors that greatly influence the yield of cultivars; among the main ones are temperature, solar radiation, precipitation, latitude, longitude, and altitude. Given this lack of information, this work aimed to evaluate the influence of meteorological variables and geographic factors on the selection of soybean lines concerning grain yield in soybean-producing regions of Brazil and Paraguay.

2. Material and Methods

The study was conducted in seven different environments: Bela Vista do Norte - PY; Palotina - PR; Mangueirinha - PR; Major Vieira - SC; Três Passos - RS; Toledo – PR, and Passo Fundo - RS. These environments had distinct meteorological variables, soil types, relief, and geographic locations.

The randomized block design in an incomplete factorial scheme with six soybean genotypes (G1, G2, G3, G4, G5, and G6) was used for the experiments. The experimental units consisted of rows 15 meters long and 6 meters wide, spaced at 0.45 meters. Sowing was carried out in the first half of October 2020, using ten seeds per meter and cultivation organically without the addition of synthetic molecules. The harvest occurred in the first half of March, and grain yield was measured through the total harvest of the plot and expressed in kg ha^{-1}, with grain moisture at 13%.

The climatic variables used in the present study were maximum air temperature (Tmax, ºC), average air temperature (Tavg, ºC), minimum air temperature (Tmin, ºC), relative air humidity (RH, %), precipitation (Prec, mm), wind speed (WS, m/s), dew point (DP, °C), incident radiation (Rad_Inc, MJ/m²), and total radiation (RAD_OL, MJ/m²). The climate variables were obtained through the Nasa Power platform (2022) via R software, EnvRtype package (R Core Team, 2022).

In addition, observation of geographic factors such as altitude, latitude, and longitude of each environment (Nasa Power, 2022). The normality of errors and homogeneity of the residual variances of the variable grain yield was analyzed. Subsequently, descriptive analysis of the genotype averages in each environment was used, represented by the heat map. Pearson's linear correlation analysis was used at 5% significance by Student's t-test to demonstrate the relationships between the evaluated variables.

The application of factor analysis was used to select the climatic covariates with the greatest contribution to the environmental variance. In addition, the reaction norm analysis was applied to understand the sensitivity of the genotypes according to the climatic covariates selected by the factorial analysis. The regression tree analysis, in which grain yield was established as a dependent variable, was used to evidence its expression through the explanatory variables. All analyzes were performed in R software version 4.1.3 (R Core Team, 2022) using the packages ggplot2, foreach, do Parallel, gge, GGEBiplots, superheat, BGLR, devtools, FW, and EnvRtype.

3. Results and Discussion

The heatmap allows the dynamic observation of the performance of genotypes, environments, and G x E interaction in the expression of grain yield (Figure 1). The G_2 and G_5 genotypes showed the lowest yields in Major Vieira - SC, Toledo - PR, and Mangueirinha - PR environments, close to 3,000 kg ha^{-1}. These environments have the highest altitudes among the environments, ranging from 550 to 921 meters, except for Passo Fundo, RS at 687 meters of altitude. The average maximum temperatures did not exceed 30 ^{o}C, between 24.74 ^{o}C and 28.96 ^{o}C. The average medium temperatures were between 18.55 ^{o}C and 22.3 ^{o}C, while the average minimum temperatures were between 13.11 ^{o}C and 16.66 ^{o}C.

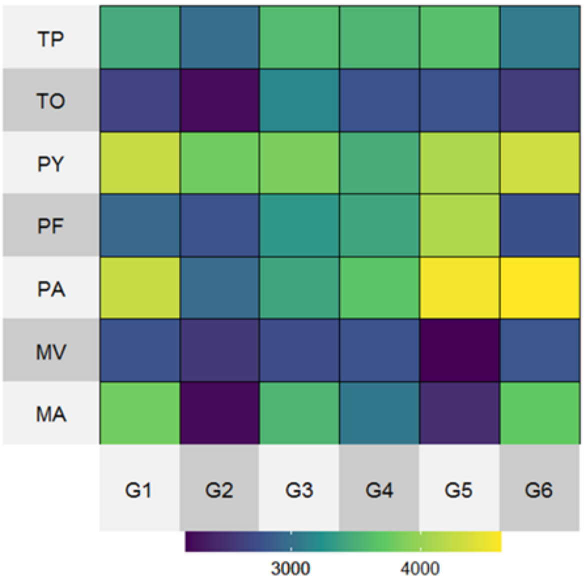


Figure 1. Heatmap corresponding to the soybean grain yield (kg ha^{-1}) of six genotypes at seven environments. Três Passos - RS (TP), Toledo - PR (TO), Bela Vista do Norte - PY (PY), Passo Fundo - RS (PF), Palotina - RS (PA), Major Vieira - SC (MV) e Mangueirinha, - PR (MA). Genotypes (G_1, G_2, G_3, G_4, G_5, and G_6)

Bela Vista do Norte - PY and Palotina - PR had the highest yields by genotypes G1, G5, and G6, exceeding 4,000 kg ha-1. Highlighted as common conditions between Bela Vista do Norte - PY and Palotina - PR the low altitudes (that do not exceed 338 meters), the lowest latitudes (from -22.07^{o} to -24.17^{o}), the maximum temperatures (between 30.28 ^{o}C and 32.6 ^{o}C), the average temperatures (between 23.26 ^{o}C and 25.52 ^{o}C), and the minimum temperatures (between 17.38 ^{o}C and 19.41 ^{o}C).

Opposite to the places of lower yields, medium temperatures remained in a higher range, between 20 ^{o}C and 30 ^{o}C, with a minimum closer to 20 ^{o}C and a maximum close to 30 ^{o}C. This higher grain yield may be directly related to the temperature because, according to Ferrari et al. (2015), the ideal temperatures for the growth and development of the soybean crop are in a range of requirement between 20 ^{o}C and 30 ^{o}C, being considered ideal the temperature of 30 ^{o}C. According to Pearson's linear correlation (Figure 2), grain yield tends to be higher when altitude decreases, with a moderate negative correlation of -0.46.

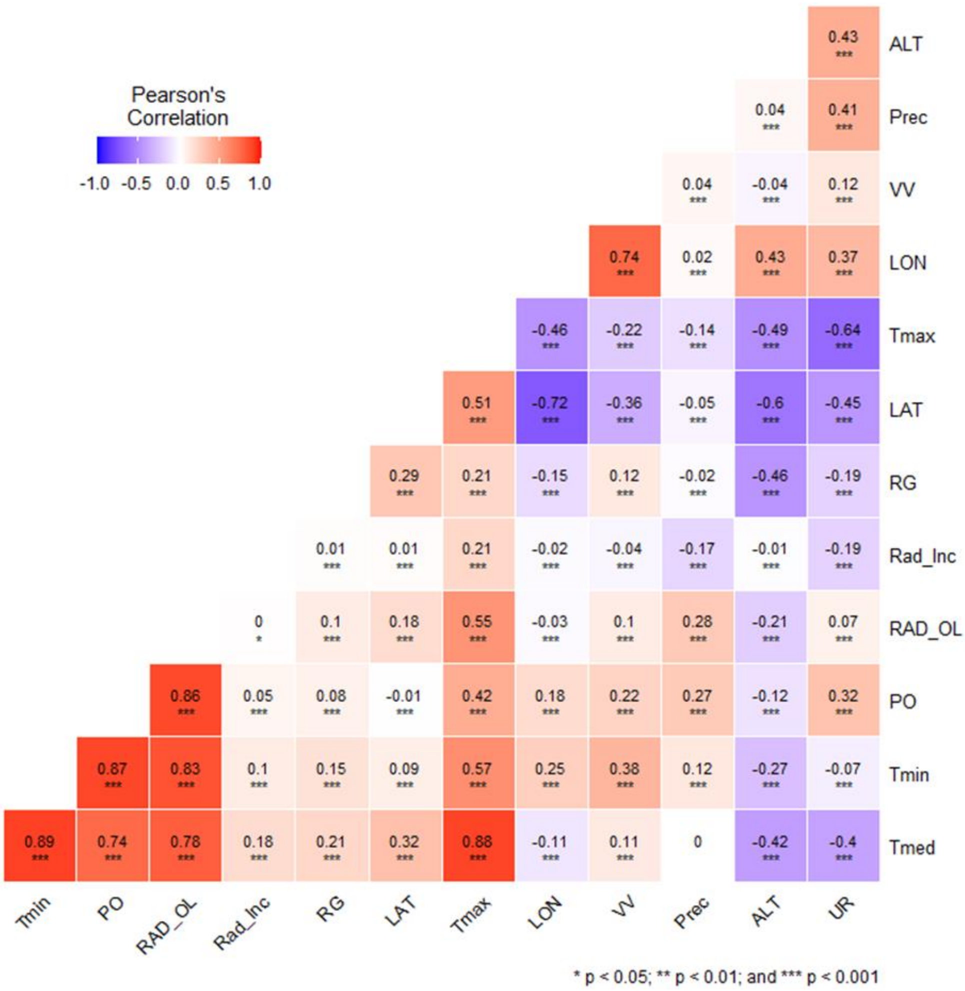


Figure 2. Pearson's linear correlation between soybean grain yield (GY) and altitude (ALT), longitude (LON), latitude (LAT), precipitation (Prec), wind speed (W), incident radiation (Rad_Inc), total radiation RAD_OL), dew point (PO), minimum temperature (Tmin), average temperature (Tavg), maximum temperature (Tmax), and relative air humidity (RH).

Maximum temperature and latitude have weak positive correlations of 0.21 and 0.29 with grain yield, and for the relative air humidity (-0.19), precipitation (-0.02), wind speed (0.12), and longitude (-0.15), the correlations are very weak. Weak positive correlations of grain yield with incident (0.01) and total (0.1) radiation and minimum (0.15) and average (0.21) temperature were found. Altitude and air temperature are factors and climatic elements that have an interconnection; generally, higher-altitude locations have milder temperatures than lower-altitude locations. This fact occurs due to the adiabatic gradient of dry air, which causes a decrease in temperature with increasing altitude (Fritzsons et al., 2016). Pearson's correlation shows lower altitudes and high maximum temperatures favor grain yield.

Latitude had a weak positive correlation with grain yield. Rocha et al. (2012) report that the life cycle is influenced by the photoperiod, which has directly relation to latitude and influences the behavior of soybean cultivars, causing them to manifest different reactions in each location. Genotypes adapted to lower latitudes exhibit a genetic component that differs from traditional growing regions. It refers to the long juvenile period, which extends the vegetative phase of soybean under short-day circumstances (Spehar et al., 2014), promoting conditions for accumulating greater amounts of photoassimilates and these being translocated to their grains (Capone et al., 2018). As a way of understanding and measuring the effects of the genotype x environment interaction, reaction norms are an important tool for estimating genotypic development in all possible production environments by using joint estimates of genetic parameters and environmental values (Nunes et al., 2018).

It can be said that there is a genotype-environment interaction effect when it is possible to identify yield differences in genotypes according to the environment to which they are exposed. For the reaction norm, note that the genotypes G_6, G_5, G_1, and G_3 obtained the highest yield averages (Figure 3).

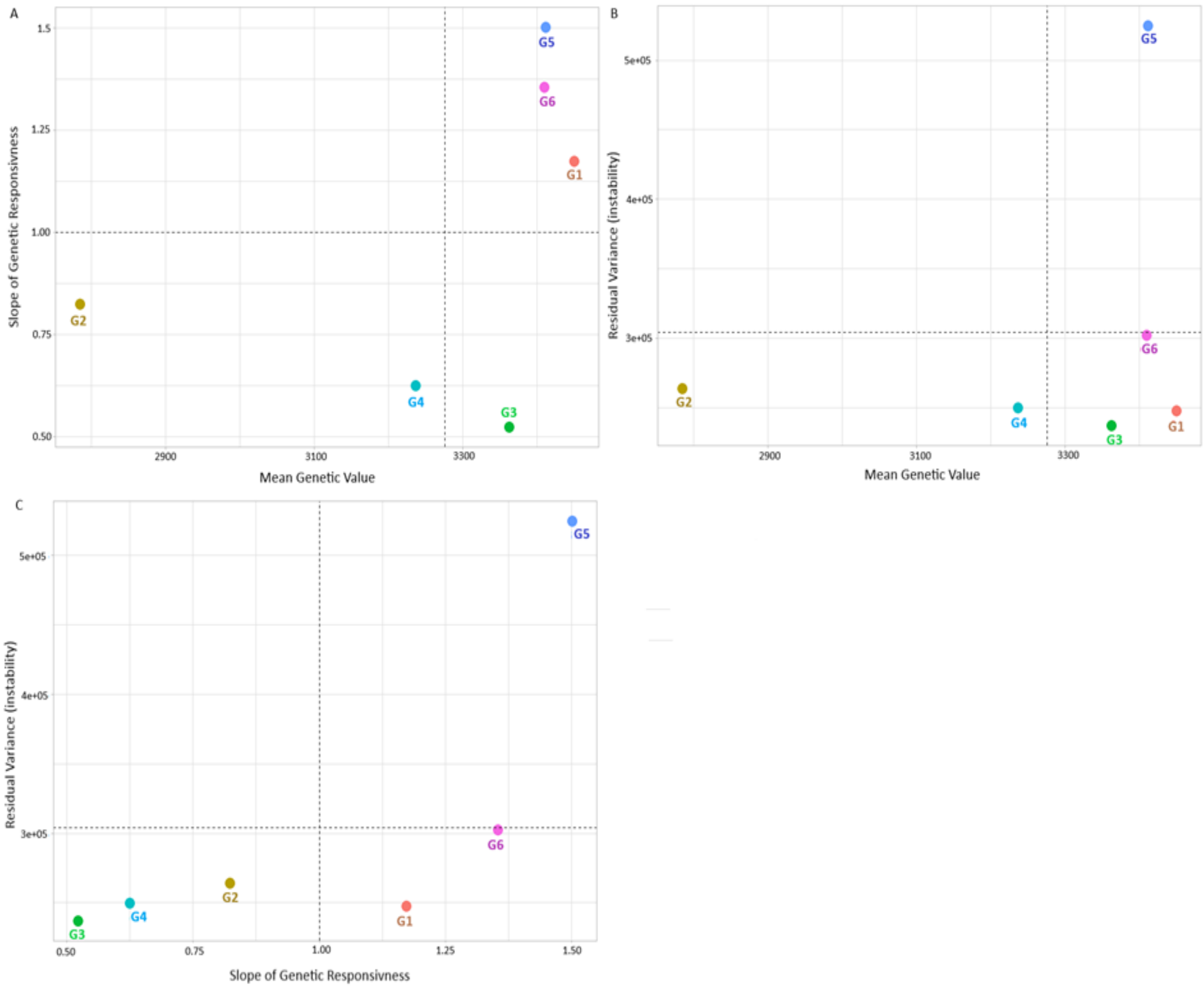


Figure 3. Reaction norm of average genetic values of grain yield (kg ha-1) and residual variance (instability) for six soybean genotypes evaluated in seven growing environments in the 2019/2020 crop season.

Among them, G_6 and G_5 are the most genetically responsive genotypes, which means that regardless of climatic factors and elements, grain yield is stable and can be predictable since a soybean cultivar must have high yield and high stability and adaptability to different growing environments (Almeida et al., 2011; Herrera et al., 2020). The reaction norm model configures an alternative model for evaluating many environments by estimating a few parameters in the model (Cobuci et al., 2013). According to the reaction norm (Figure 4), the altitude variable positively influenced all genotypes, as mentioned in the descriptive analysis. Costa et al. (2019) report that higher yields are achieved in places of higher altitudes due to lower night temperatures, which allow greater accumulation of photoassimilates due to the lower respiration rate.

Greater longitudes have influenced most genotypes, where at higher longitudes, the G6 and G5 genotypes were more responsive, while at lower longitudes, G_1 and G_3 showed better responsiveness. The average temperature influenced most genotypes (Figure 4). Higher latitudes positively influenced the G_1, G_2, and G_6 genotypes, while lower latitudes favored the G_3, G_4, and G_5 genotypes (Figure 4). The maximum temperature negatively influenced all genotypes with low magnitude, as well as the minimum temperature, except for the G_2 genotype, which was positively influenced by higher minimum temperatures (Figure 5).

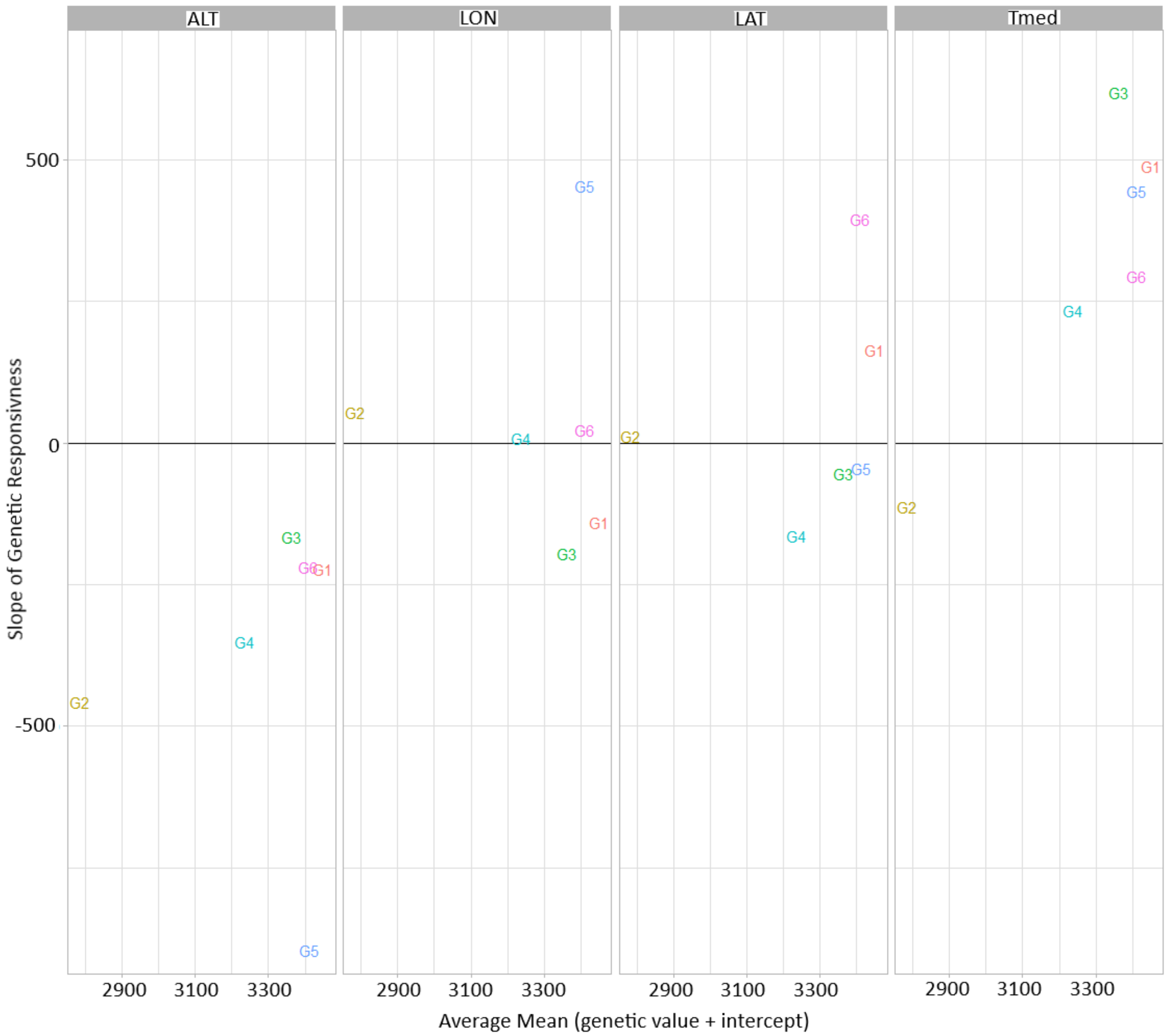


Figure 4. Responsiveness stratified by climatic variables: altitude (ALT), longitude (LON), latitude (LAT), and average air temperature (Tavg, ºC) for six soybean genotypes (G) evaluated in seven growing environments (E) in the 2019/2020 crop season.

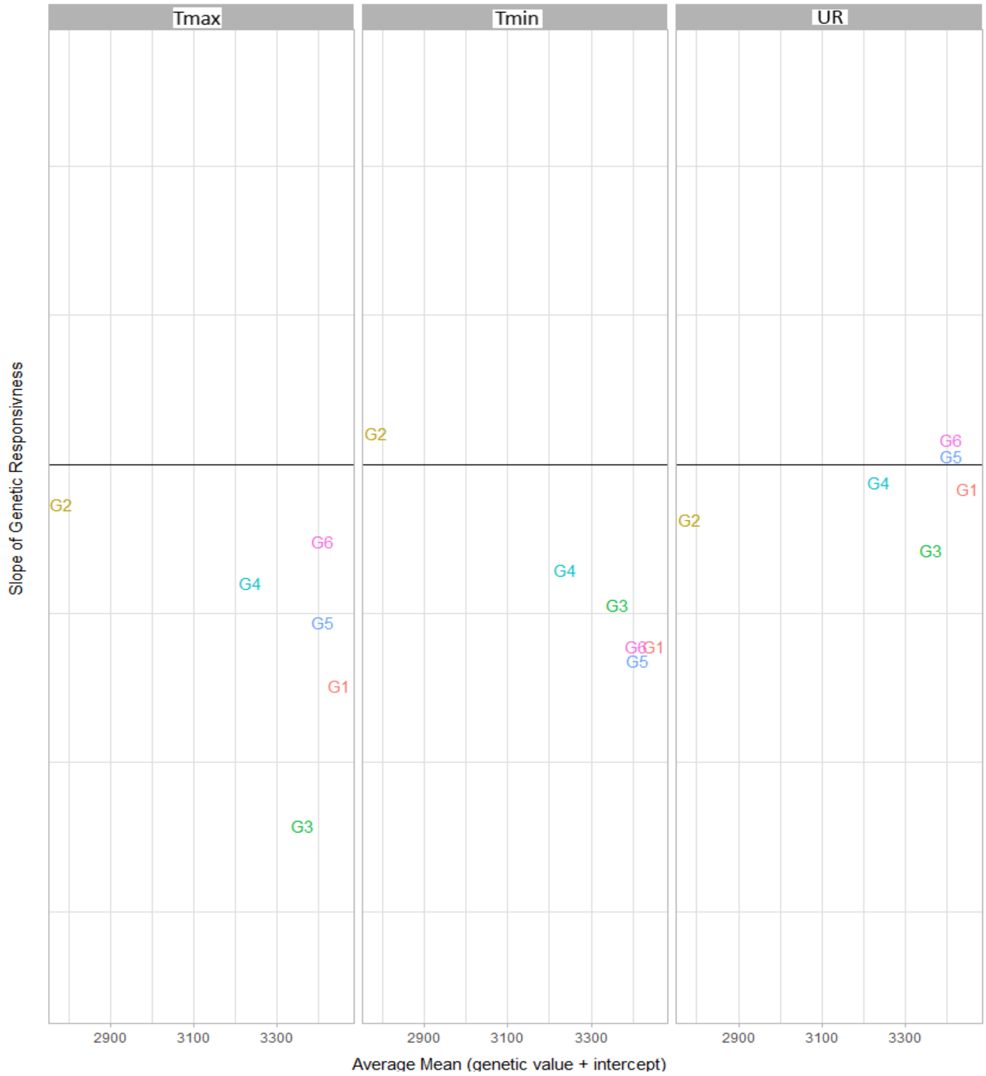
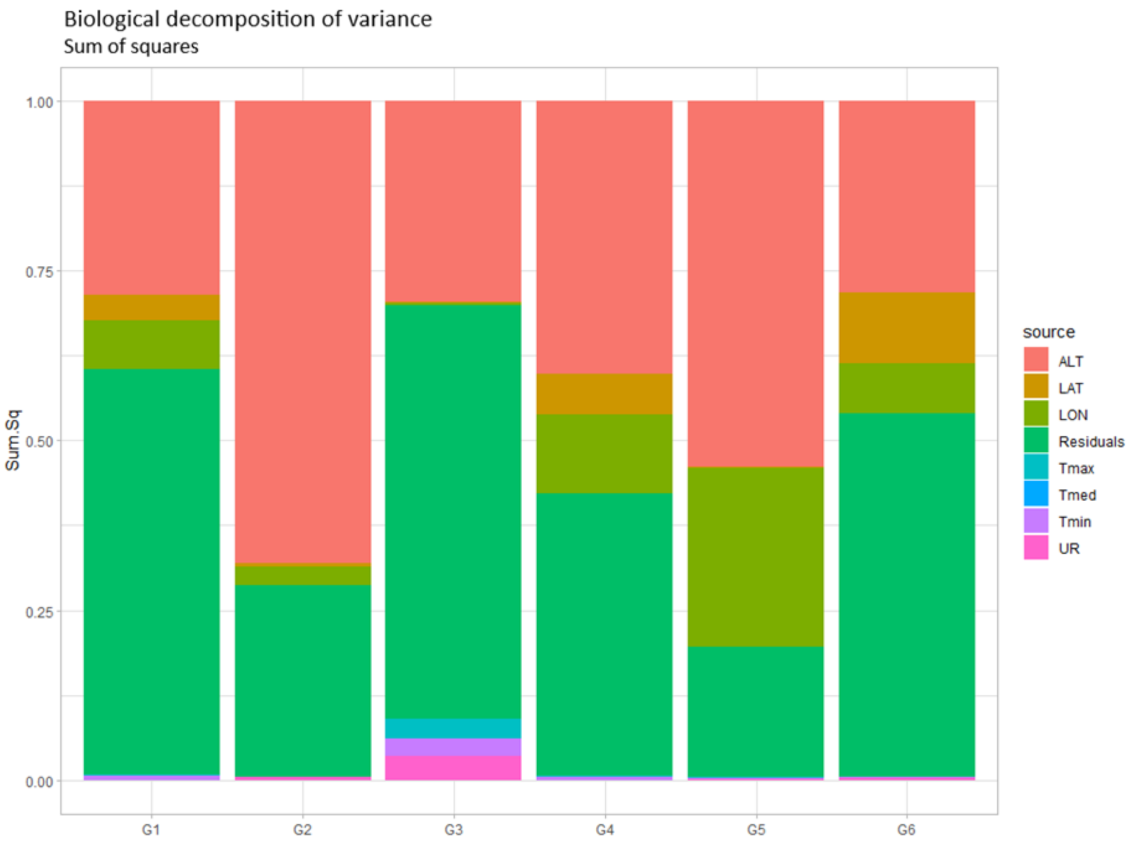


Figure 5. Responsiveness stratified by climatic variables: maximum air temperature (Tmax, ºC), minimum air temperature (Tmin, ºC), and relative air humidity (RH, %) for six soybean genotypes (G) evaluated in seven growing environments (E) in the 2019/2020 crop season.

The decomposition of the environmental variability of the variance represents the degree of influence of each geographic and climatic variable on the genotypes, where the mean square shows the total variance deduced from each variable without the residue, and the mean square is the variance of the variables with the residue. The genetic values + intercept enhancement when the genotypes are above the abscissa indicates a positive slope coefficient. Therefore, we look for genotypes with high genetic value + intercept and low negative sensitivity to environmental variables. The greatest causes of interferences were geographic factors (altitude, latitude, and longitude) on the genotypes G_1, G_2, G_4, G_5, and G_6 (Figure 6). Genotype G3 is different from the others; it obtained a high influence of the climatic elements compared to other genotypes.

In the regression tree of climatic factors on grain yield, the decision-making starts from the altitude, in which less than or equal to 338 meters presents a yield greater than 3900 kg ha^{-1} (Figure 7). In this scenario, if the latitude is less than or equal to -24.17^{o}, its yield is estimated to be close to 3914 kg ha^{-1} as in Palotina - PR and Bela Vista do Norte - PY

For altitudes above 338 meters, the decision-making is based on latitudes less than or equal to -27.292^{o} that leave for another branch where the longitudes less than or equal to -53.54^{o} tend to produce 3.372 kg ha$^{-1,}$ which is the case of Mangueirinha - PR, Major Vieira - SC, Toledo - PR and Três Passos - RS. Moving to latitudes greater than or equal to -27.29^{o,} it arrives at another branch taking into account the altitude; if it is less than 786 meters and latitude greater than -26.22^{o,} the environment will produce around 2.695 kg ha^{-1}, which is the case of Passo Fundo - RS. According to Zdziarski et al. (2018), the insertion of genes for the juvenile period made it possible for soybean to adapt to an environment with low latitudes and its expansion to the most diverse environments. In this way, the use of maturity groups to recommend cultivars to areas of better adaptation to maximize their grain yield.



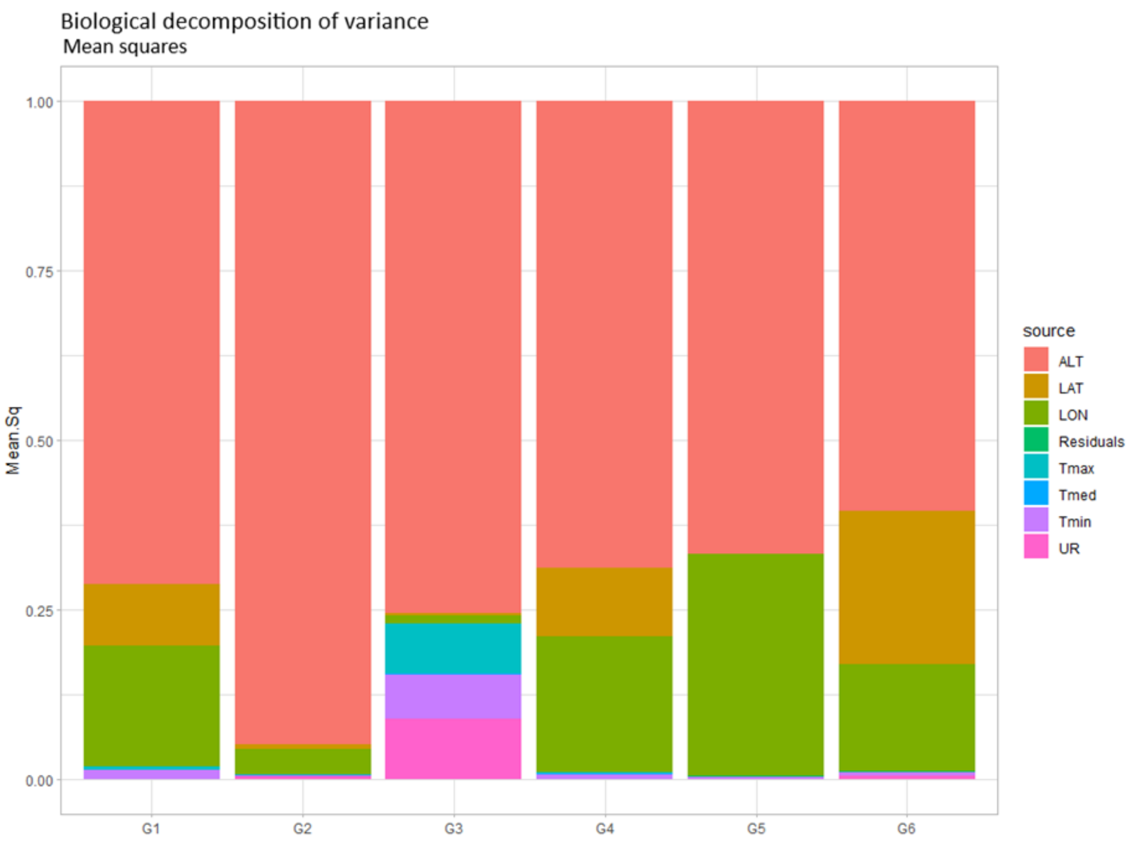


Figure 6. Decomposition of the environmental variability of variance into climatic covariates: maximum air temperature (Tmax, ºC), average air temperature (Tavg, ºC), minimum air temperature (Tmin, ºC), relative air humidity (RH, %), latitude (LAT), altitude (ALT), and longitude (LON) for six soybean genotypes (G) evaluated in seven growing environments (E) in the 2019/2020 crop season.

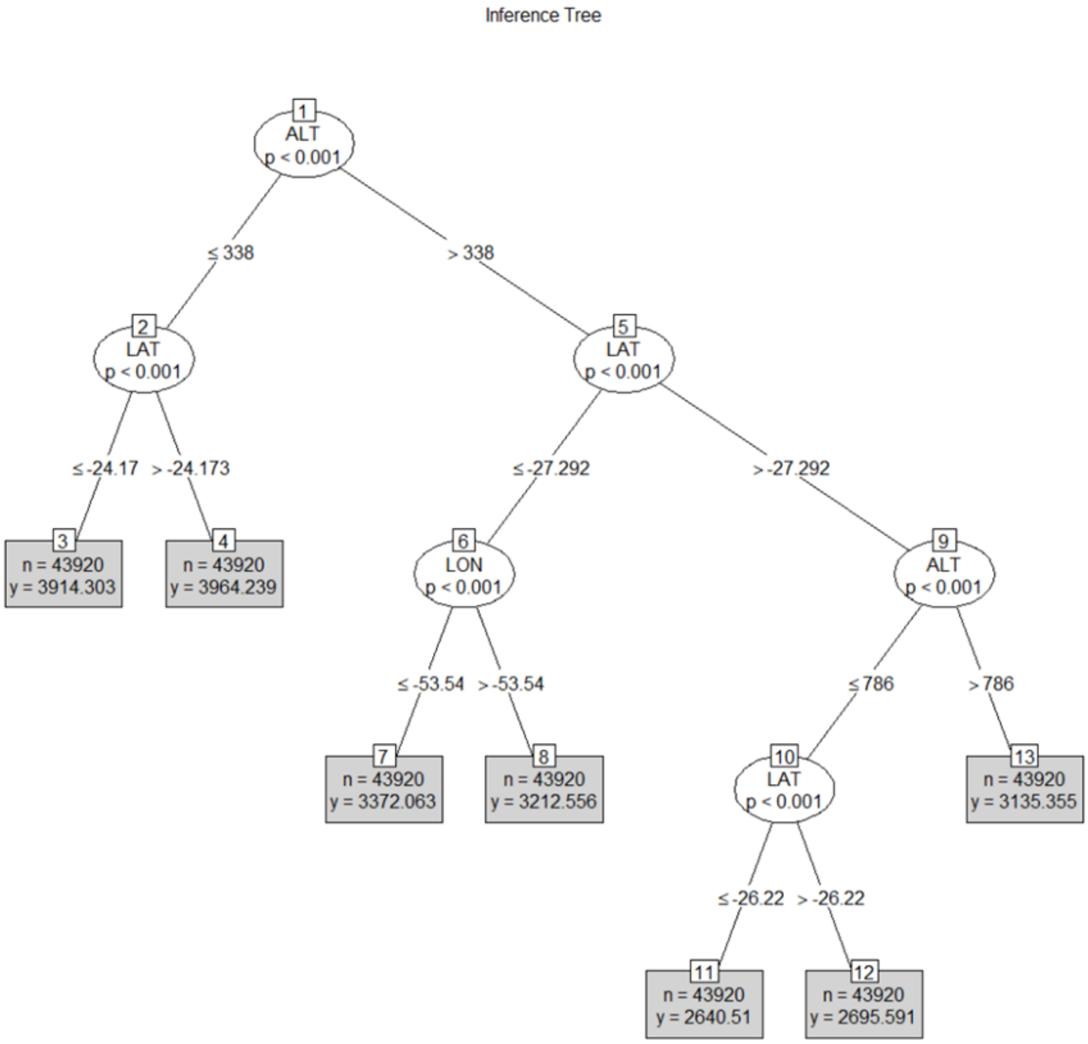


Figure 7. Regression tree for the dependent variable (grain yield) in which the branches indicate the independent variables altitude (ALT), latitude (LAT), and longitude (LON).

4. Conclusions

The G_3 genotype is characterized by greater stability and adaptation to unfavorable environments with average grain yield above the general average. The G_5 genotype with a genetic value for grain yield above the general mean is the most adapted to favorable environments. Altitude had the greatest influence on the biological variability of the genotypes, with a negative correlation of moderate magnitude with grain yield. Grain yield was enhanced in environments with altitudes lower than 338 m at latitudes below 24.17S.

Authors' Contribution

Victor Delino Barasuol Scarton: writing and conducting the essay in Três Passos-RS; Ivan Ricardo Carvalho: writing, advisor and data analysis; Leonardo Cesar Pradebon: conducting the test in Toledo-PR; Murilo Vieira Loro: conducting the test in Passo Fundo-RS; Aljian Antônio Alban and Marcio Alberto Challiol: conducting the test in Bela Vista do Norte-PY; Natália Hinterholz Sausen and Pedro Modesto Fagundes Braga: conducting the test in Toledo-PR; Inaê Carolina Sfalcin: conducting the test in Major Vieira-SC.

Bibliographic References

Almeida, R.D., Peluzio, J.M., Afférri, F.S. 2011. Divergência genética entre cultivares de soja, sob condições de várzea irrigada, no sul do Estado Tocantins. Revista Ciência Agronômica, 42(1), 108-115.

Capone, A., Santos, E.R., Santos, A.F., Dario, A.S., Barros, H.B. 2018. Produtividade e qualidade de sementes de genótipos de soja para alimentação humana introduzidos em Tocantins, na entressafra. Nucleus, 15(1), 71-84. DOI: https://doi.org/10.3738/1982.2278.2171

Carvalho, C.G.P., Arias, C.A.A., Toledo, J.F.F., Almeida, L.A., Kiihl, A.S., Oliveira, M.F. 2002. Interação genótipo x ambiente no desempenho produtivo da soja no Paraná. Pesquisa Agropecuária Brasileira, 37(7), 989-1000. DOI: https://doi.org/10.1590/S0100-204X2002000700013

Cobuci, J.A., Costa, C.N., Cardoso, F.F., Braccini Neto, J., Ambrosini, D.P., Moura, M.D. 2013. Interação genótipo-ambiente na raça holandesa utilizando modelo de norma de reação. X Simpósio brasileiro de Melhoramento animal, 10, Uberaba. Anais..., Viçosa. Sociedade Brasileira de Melhoramento Animal. https://ainfo.cnptia.embrapa.br/digital/bitstream/item/97771/1/Cobuci-et-al.-SBMA-2013.pdf

Costa, R., Silva, A.G., Simon, G.A., Bessa, E.R., Dias, M.O. 2019. Agronomic performance of transgenic soybean cultivars in brazilian cerrado. Acta Scientiarum. Agronomy, 41, e42713. DOI: https://doi.org/10.4025/actasciagron.v41i1.42713

FAO. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Production of Soybeans: top 10 producers. 2020. https://www.fao.org/faostat/en/#data/QCL/visualize. (accessed June 24, 2022).

Ferrari, E., Paz, A., Silva, A.C. 2015. Déficit hídrico e altas temperaturas no metabolismo da soja em semeaduras antecipadas. Nativa, 3(1), 67-77. DOI: https://doi.org/10.31413/nativa.v3i1.1855

Fritzsons, E., Mantovani, L.E., Wrege, M.S. 2016. Relação entre altitude e temperatura: uma contribuição ao zoneamento climático no estado de Santa Catarina, Brasil. Revista Brasileira de Climatologia, 18(12), 80-92. DOI: http://dx.doi.org/10.5380/abclima.v18i0.39471

Gazzoni, D.L. 2018. A soja no Brasil é movida por inovações tecnológicas. Ciência e Cultura, 70(3), 16-18. DOI: http://dx.doi.org/10.21800/2317-66602018000300005

Herrera, G.C., Poletine, J.P., Brondani, S.T., Antônio, M., Barelli, A., Silva, V.P. 2020. Adaptabilidade e estabilidade de linhagens de soja na região sul do Brasil por meio de modelagem mista. Journal of Agronomic Sciences, 9, 185-202.

NASA POWER. 2022. NATIONAL AERONAUTICS AND SPACE ADMINISTRATION. Prediction of Worldwide Energy Resources. https://power.larc.nasa.gov/ (accessed June 10, 2022).

Nunes, D., Assis, J. R., Tavares, S. G., Oliveira, P. H. L. 2018. Models of reaction standards for analysis of effects of interaction genotype environment. Scientific Electronic Archives, 11 (4), 122-128.

ONU. ORGANIZAÇÃO DAS NAÇÕES UNIDAS. Perspectivas Mundiais de População 2019: Destaques, 2019. https://brasil.un.org/pt-br/83427-populacao-mundial-deve-chegar-97-bilhoes-de-pessoas-em-2050-diz-relatorio-da-onu. (accessed June 10, 2022).

R Core Team. 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/. (accessed June 01, 2022).

Rocha, R.S., Silva, J.A.L.D., Neves, J.A., Sediyama, T., Teixeira, R.D.C. 2012. Desempenho agronômico de variedades e linhagens de soja em condições de baixa latitude em Teresina-PI. Revista Ciência Agronômica, 43(1), 154-162. DOI: https://doi.org/10.1590/S1806-66902012000100019

Saath, K.C.O., Fachinello, A.L. 2018. Crescimento da demanda mundial de alimentos e restrições do fator terra no Brasil. Revista de Economia e Sociologia Rural, 56(2), 195-212. DOI: https://doi.org/10.1590/1234-56781806-94790560201

Spehar, C.R., Francisco, E.R., Pereira, E.A. 2014. Yield stability of soybean cultivars in crop seasons and sowing dates at low latitude Brazilian Savannah Highlands. Journal of Agricultural Science, 153(6), 1059-1068. DOI: http://dx.doi.org/10.1017/s0021859614000781

Zdziarski, A.D., Todeschini, M.H., Milioli, A.S., Woyann, L.G., Madureira, A., Stoco, M.G., Benin, J. 2018. Principais grupos de maturidade da soja para aumentar a produtividade de grãos no Brasil. Crop Science, 58(3), 1155-1165. DOI: https://doi.org/10.2135/cropsci2017.09.0581