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Use of geographic and edaphoclimatic information for the selection of soybeans for organic environments in current and future scenarios

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ABSTRACT

The objective of this work was to select soybean genotypes for different organic growing environments, based on geographic and soil climatic information and use of predictions of meteorological variables for future scenarios. The experiment was conducted in a randomized block design, in an incomplete factorial scheme, with three agricultural harvests (2019/2020, 2020/2021 and 2021/2022) x 21 environments organics x 18 conventional soybean genotypes, arranged in three replications per environment. The study was di-vided into two agricultural scenarios based on soybean grain productivity, where scenario I was based on variable data on minimum temperature, mean temperature, maximum temperature, precipitation, relative humidity, incident radiation, in addition to geographic variables such as latitude, longitude and altitude. The scenario II was predicted based on data from 2023 to 2040 through climate projections, from the INPE were used.The genotypes LIN 16, BRS 539 and IPR 115 are superior in terms of grain productivity. The BRS 511 genotype had a high genetic average, high responsiveness to improvements in the growing environment and high stability. In the current scenario, latitude, soil pH and soil organic carbon stock are determining factors for the grain yield of genotypes destined for organic management. In the future scenario, the minimum, mean and maximum air temperatures will be the basis for positioning soybeans in organic conditions. The year 2026 will be the most critical for soybean production in southern Brazil due to low precipitation and high temperatures. In this context, it is envisaged to select cultivars that tolerate hot environments and are resilient to water restrictions. To guarantee their potential, it is necessary to provide environments with high fertility, vegetation cover and minimal interspecific competition with other plant species.

Keywords: *Glycine max* L., grain productivity, positioning of genotypes, selection.

INTRODUCTION

Soybean (*Glycine max* L. Merrill) is an oilseed belonging to the Fabaceae family, which is of great importance in Brazilian and global agribusiness. Soy protein is one of the high-quality vegetable proteins that have important health benefits. It is rich in eight essential amino acids, vitamins, flavonoids and polysaccharides.[1,2] The multiple purposes of its grains in the production of food, medicines and chemical products have promoted a continuous increase in demand, in addition to the rapid development of the soybean industry.[1]

According to a survey by the Food and Agriculture Organization, global production of this oilseed was 371.17 million tons of grains in 2023, with the American continent responsible for 84.2% of world production.[3] Brazilian production for the 2024/2025 harvest is estimated at 166.3 million tons of grains, an increase of 12.6% compared to the previous harvest.[4] Although soybeans have reached high levels of productivity, new investments are essential for research and development of new cultivars, as well as management and technologies that result in greater sustainability for the soybean production chain.[5]

In this way, organic agriculture is an attractive alternative from a sustainable, economic and environmental point of view, combined with a high demand for products free of synthetic molecules, in addition to higher benefit. Study carried out by Hartamann,[6] highlights that the consumption of organic soybeans in the United States of America has been growing over the years, where in 2014, the value of imports of organic soybeans was 184 million dollars, an increase of 348% compared to 2011. Although this system of cultivation has many advantages, there are still large gaps in obtaining high productivity and safety in crop cultivation. The positioning of genotypes in these systems requires specific studies, since chemical fertilization and pest and disease control are not used in this environment.[5]

Toleikiene,[7] when evaluating organic soybean production in Europe, they observed grain yields between 673 and 3154 kg ha^{-1}. The authors conclude that management practices significantly affect the productivity and quality of soybeans, with a strong influence on the sowing date. However, according to Murphy,[8] the main limitation of organic production is the lack of cultivars adapted to this system, and the dependence on cultivars developed for the conventional cultivation system and thus do not represent the conditions present in organic agriculture. Due to the high influence of abiotic factors on soybean productivity, genetic improvement programs have been shaped to develop genotypes superior in grain productivity, greater nutritional value and mainly tolerant to abiotic stresses, in addition to more adapted and stable genotypes in the most varied agricultural regions.[9]

According to Scarton,[10] meteorological and geographic factors are determining factors in grain productivity. The water deficit is the main limiting factor for soybeans in current Brazilian climate conditions. Still Silva[11] observed a reduction in the duration of the soybean crop cycle, because of increased temperature and water stress, which directly influence the crop stages. Similar results were observed by Santos,[12] when evaluating the effect of temperature on corn and soybean productivity, reported that the increase in extreme maximum temperatures and diurnal thermal amplitude indices are environmental factors that negatively impact the production of rainfed crops in Nebraska-USA.

Due to the need to promote the positioning of soybean cultivars in an assertive manner, reducing the interference of external and climatic factors, the objective of this work was to select soybean genotypes for different organic growing environments, based on geographic and soil-climatic information and use of predictions of meteorological variables for future scenarios.

MATERIAL AND METHODS

This study was carried out in 21 cultivation environments, distributed across five Brazilian states and also one environment located in Paraguay, namely: Augusto Pestana- RS, Bela Vista do Norte- PY, Capinzal- SC, Diamante D'Oeste- PR, Dourados- MS, Entre Rios do Oeste- PR, Faxinal dos Guedes- PR, General Câmara- RS, Jaboticabal- SP, Laguna- MS, Major Vieira- SC, Mangueirinha- PR, Maracajú- MS, Palmital- SP, Palotina- PR, Passo Fundo- RS, Salto do Lontra- PR, São Francisco de Paula- RS, Tiradentes do Sul- RS, Toledo- PR and Três Passos- RS.

The experiment was conducted in a randomized block design, in an incomplete factorial scheme, with three agricultural harvests (2019/2020, 2020/2021 and 2021/2022) x 21 environments x 18 conventional soybean genotypes (BRS 284, BRS 511, BRS 525, BRS 537, BRS 539, BRS 6013, BRS 391, BRS 523, DF 2353, GE, LIN 16, INT 3438, BRS 546, BRS 531, BRS 573, IPR 110, IPR 115 and IPR 122), arranged in three replications per environment. The experimental units were composed of rows 15 meters long and six meters wide, spaced 0.45 m apart. Sowing was carried out in the first half of October 2019, 2020 and 2021, with a density of 10 seeds per linear meter, and cultivation organically, without the addition of synthetic molecules. For the previous crops, *Pennisetum glaucum* was used for the environments located in PY, MS, and SP, and *Avena sativa* for the environments located in PR, RS, and SC. Rolling (knocking down with a knife roller) was subsequently performed when the crops were at the full flowering stage. Weed management was carried out through manual weeding in order to minimize biotic effects on the experimental results.

SCENARIO I - evaluation was carried out based on the variable grain yield (kg ha^{-1}). For the first scenario, geographic and climatic data were used that occurred in the years 2019, 2020, 2021 and 2022. The latitude (LAT), longitude (LON) and altitude (ALT) of the cultivation environments were obtained through Google Earth.[13] Climatic data on minimum temperature (Tmin, ºC), mean temperature (Tmed, ºC), maximum temperature (Tmax, ºC), precipitation (Prec, mm), relative humidity (RH, $g.kg^{-1}$) and incident radiation (Rad, $MJ.m^2.day^{-1}$) were obtained through NASA Prediction of Worldwide Energy Resources.[14]

SCENARIO II - for the predicted scenario, with data from 2023 to 2040, climate projections (pclimate) from the National Institute for Space Research[15] were used, where the values for the variables minimum temperature (Tmin, ºC) were projected), mean temperature (Tmed, ºC), maximum temperature (Tmax, ºC), relative air humidity (RH, %), precipitation (Prec, mm) and incident radiation (Rad, $MJ.m^2.day^{-1}$).

Edaphic data on organic carbon density (DCO, g.dm3), organic carbon stock (OCS, ton ha^{-1}), soil density (DS, cg.dm3), clay content (CC, $g.kg^{-1}$), cation exchange capacity (CTC, mmol(c) kg^{-1}), nitrogen content (N, $cg.kg^{-1}$) and soil hydrogen potential (pH were obtained through Soil Grids.[16] The projections were based on soil and climate variables, without the application of crop growth models. Climate data were derived from projections for the period 2023 to 2040, while soil variables were obtained from SoilGrids. These variables served as predictors in the regression model to estimate future grain yield, the dependent character was grain yield, while the independent variables were Tmed, Tmin, Tmax, RH, Prec and Rad.

The data used in this study were extracted from the GitHub repository[35]. An analysis of the assumptions of normality of errors and homogeneity of residual variances of the variables involved in scenarios I and II was carried out. Subsequently, Biplot main components analysis was used to highlight the multivariate trend of geographic and edaphoclimatic attributes depending on the cultivation environments. In order to better visualize the measures of central tendency, heatmaps were created using the method based on Restricted Maximum Likelihood (REML) in order to estimate the components of variance and genetic parameters, where significance was obtained through *Deviance* analysis at 5% probability using the Chi-square test (χ^2).

The REML/BLUP estimates and predictions were applied in a general and stratified manner to the test environments for the specific recommendation of cultivars and lines adapted to a given region, based on the performance of the cultivars. The reaction standard was applied with the purpose of identifying genetic performance weighted by the action of an environmental index, genetic instability and responsiveness. Subsequently, factorial regression was used, setting grain productivity as the dependent characteristic and the other geographic and edaphoclimatic variables as explanatory covariates of the models. The analyzes were carried out using the software R version 4.1.3[17] through the packages ggplot2,[18] foreach,[19] Parallel,[17] superheat, BGLR, devtools, metan,[20] FW and EnvRtype.

RESULTS AND DISCUSSION

SCENARIO I

It is possible to demonstrate a better understanding of the similarity of environments depending on meteorological and soil variables through principal component analysis. According to Biplot principal component analysis (Figure 1), it was observed that the first two components presented an explainability of 65.94% (PCAI-54.3%; PCA2- 11.64%) of the data variability. In this way, it was inferred that the environments Toledo- PR, Augusto Pestana- RS, Três Passos- RS, Maracaju- MS and Dourados- MS showed greater similarity in terms of CTC, N and DCO levels. On the other hand, Salto do Lontra- PR, Faxinal do Guedes- SC, Capinzal- SC and Mangueirinha- PR, showed affinity for Tmax, Tmed, RH and DS. Associations with Tmin, Rad, pH, LAT and PREC were observed for the environments of São Francisco de Paula- RS, Passo Fundo- RS, Jaboticabal- SP, Palmital- SP, General Câmara- RS and Bela Vista do Norte- PY. Finally, the environments of Palotina- PR, Major Vieira- SC, Tiradentes do Sul- RS, Diamante D'Oeste- PR and Entre Rios do Oeste- PR were predisposed to present high affinity with the variables OCS, CC, LON and ALT.

It was observed that the contrasting environment corresponded to Três Passos- RS, whose genotypes IPR 122, LIN 15 and IPR 115 showed high grain productivity between 3.9 and 5.3 tons of grains ha^{-1}. This indicated that these genotypes are promising for cultivation in an organic system in this environment.[5] The lowest performing environment was Laguna-MS, with grain productivity between 0.61 and 1.89 ton ha^{-1}. This environment had a low soil organic density and pH of 5.4. Study by Hammad,[21] state that organic carbon has positive effects on soil properties such as density and pH, Hijbeek,[22] conclude that the organic carbon (OC) content of the soil is one of the main indices of soil fertility.

The occurrence of genetic variability can be observed (Table 1), in relation to grain productivity, as well as there was an interaction between genotype × environment, for soybean grain productivity, these results corroborate those observed by Gonçalves,[23] Evangelista[24] and Silva.[25] The significance of the G × E interaction can affect the selection of the best genotypes, making it difficult for breeders to recommend new cultivars. According to Cruz,[26] quantitative characters, demonstrate complex inheritance, as they are governing by a high number of genes with small effects and highly influenced by the action of the environment in which the genotype is inserted.[26] Given this, it can be inferred that the heritability presented in the REML analysis for grain productivity was low (4.2%), indicating a 96.8% influence of the environment on the expression of this characteristic.

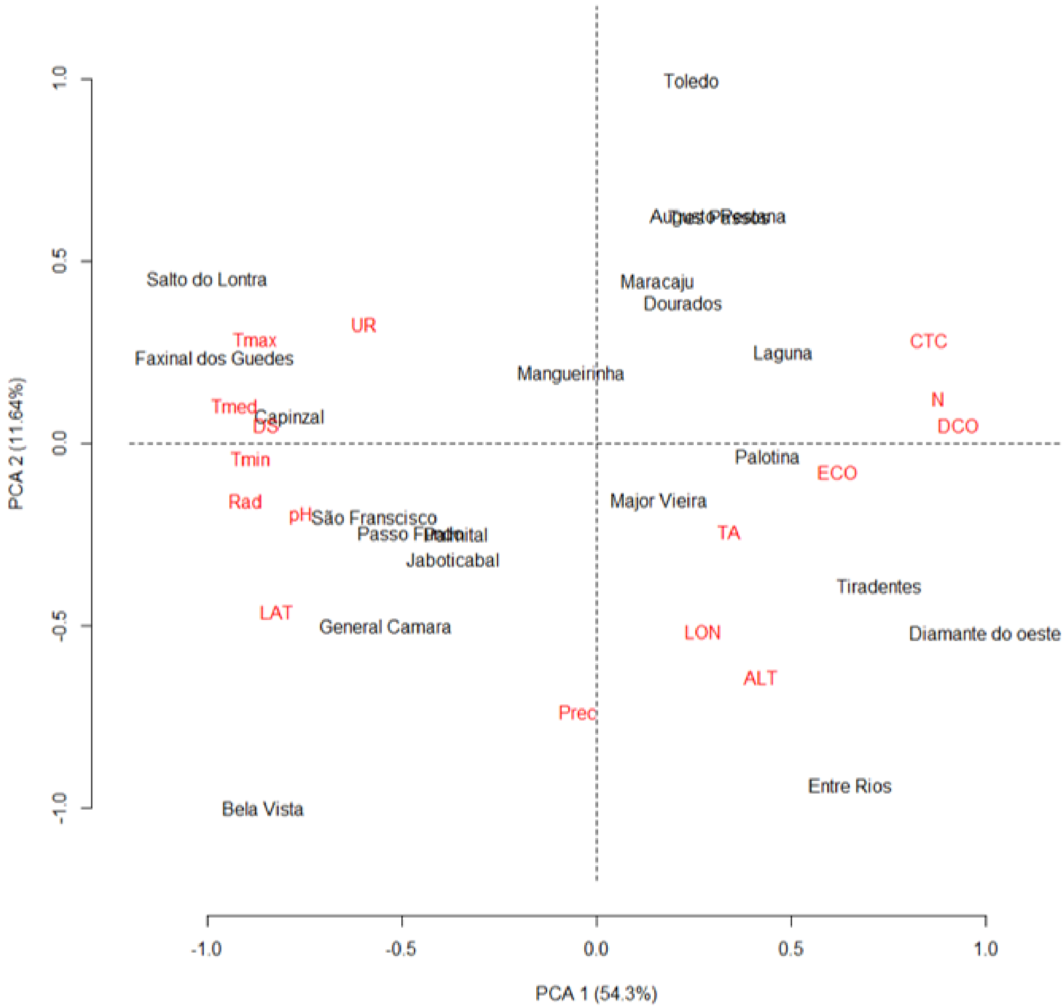

Figure 1. Biplot Main Component Analysis, highlighting the interactions between edaphoclimatic variables and cultivation environments. RH: relative air humidity; Tmax: maximum air temperature; Tmed: mean air temperature; DS: soil density; Tmin: minimum air temperature; Rad: incident radiation; pH: soil hydrogen potential; LAT: latitude; CTC: soil cation exchange capacity; N: soil nitrogen content; DCO: soil organic carbon density; OCS: soil organic carbon stock; CC: soil clay content; LON: longitude; ALT: altitude.

Table 1. Estimates of variance components and genetic parameters for soybean grain productivity grown in 21 environments in Brazil and Paraguay

VAR	MODEL	npar	LOG LIK	AIC	LRT	PR (> CHISQ)
GY	GEN	90	-998	2176	1.89	1.70 e-1*
GY	GEN:ENV	90	-1083	2346	172.	3.36 e-39*
Parameters					GY	
σ^2P					1.200	
H^2					0.042	
$GEIr^2$					0.419	
H^2mg					0.624	
Accuracy					0.790	
RGE (%)					0.437	
CVg (%)					7.480	
CVr (%)					26.80	
CV ratio (%)					0.278	

Var: Variable; Model: Model; Log Lik: Restricted Maximum Likelihood Logarithm; AIC: Informational Criterion. σ^2P: phenotypic variance; H^2: heritability in the broad sense; $GEIr^2$: coefficient of determination of the effects of the genotype-environment interaction; H^2mg: Heritability of the genotype mean.

The coefficient of determination of the effects of the genotype × environment interaction ($GEIr^2$) allows inferring the participation of the effects of the interaction, thus it was observed that 41.9% of the grain yield comes from the interaction (Table 1). Regarding the average heritability of genotypes (H^2mg), it is estimated when using averages as an evaluation or selection unit.[27] Thus, average heritability values of the genotypes were found (0.62), similar values were observed by Pradebon,[5] Albuquerque,[28] Gonçalves,[23] Albuquerque.[29] Accuracy allows us to infer the reliability of the estimates, of which a value of 0.79 was observed, characterizing the study with high precision. The genotypic correlation between the performance of genotypes × environment (RGE) was low (0.43), indicating the presence of a simple interaction. The coefficient of genotypic variation (CVg), low values were observed (5.93%), which indicates low genetic contribution in the expression of variability, with the genotypes being strongly influenced by the environment in the expression of the phenotype. The residual coefficient of variation (CVr) refers to the experimental error, where an average value (26.8%) is observed, indicating the precision of the experiment. In relation to the coefficient of variation of the proportion between the genotypic and residual coefficient of variation (CVratio), for grain productivity, it was low 0.278.

The use of genetic evaluation techniques, based on mixed models of the REML/BLUP type, are important for predicting additive and genotypic genetic values of individuals with potential for selection.[30] Thus, with selection via BLUP (Figure 2), it was observed that the genotypes Lin 16, BRS 539, IPR 115, IPR 122, DF 2353, BRS 511 and BRS 546 presented superior performance for grain productivity and are therefore located above the selection strip.

This type of analysis makes it possible to identify genotypes with predictable behavior in relation to grain productivity and that are responsive to environmental variations, as in the REML/BLUP graph (Figure 3), it is possible to observe the behavior of the genotypes in each environment evaluated. In the Augusto Pestana-RS and Jaboticabal environments, all genotypes evaluated in these environments performed better than the experiment average (2.83 ton ha^{-1} of grains). On the other hand, in Dourados- MS, Laguna-MS and Palmital- SP, no genotype had superior performance, indicating unfavorable environments. Capinzal- SC and Faxinal do Guedes- SC, the BRS 539 and BRS 525 genotypes were selected. Bela Vista do Norte- PY, only the BRS 391 genotype was inferior. Meanwhile, the INT 3438 and BRS 573 genotypes did not obtain high yields in any of the 21 cultivation environments evaluated, characterizing themselves as low-yielding genotypes, as they did not exceed the limit of 2.83 ton ha^{-1} of grains.

As for the reaction norm that compares the genetic average with the genetic responsiveness of the genotypes to improvements in the cultivation environment (Figure 4a), the genotypes BRS 511, BRS 539, DF 2353 and LIN 16 are classified as highly responsive genotypes and high genetic average. However, the IPR 115 and IPR 122 genotypes showed a high genetic average, but low responsiveness to the environment. However, the IPR 115 and IPR 122 genotypes showed a high genetic average, but low responsiveness to the environment. The reaction norm comparing the genetic average and stability of the genotypes (Figure 4b), revealed that the genotypes BRS 6013, IPR 115 and BRS 511, with high genetic average and high stability. According to Scarton[10] and Herrera[31] regardless of climatic factors and elements, grain yield is stable and can be predictable, as a soybean cultivar must have high yield and high stability and adaptability to different growing environments. When considering genetic responsiveness to different environments with stability (Figure 4c), it was found that the BRS 511 and BRS 284 genotypes showed high stability and above-average responsiveness. On the other hand, the genotypes IPR 110, IPR 115, BRS 546 and BRS 115 showed the worst performance, with low stability and low responsiveness in improving environments.

The decomposition of environmental variability of variance represents the degree of influence of each geographic and climatic variable on the genotypes (Figure 5). It was observed that the genotypes BRS 511 and BRS 537 are highly influenced by latitude and longitude, similar performance was observed for Lin 16, which had a greater contribution to the phenotypic expression of the genotype. Similar results were observed by Scarton,[10] where the biggest causes of interference in the phenotypic expression of six soybean genotypes came from geographic factors. Soil pH explained between 10.70 and 44.9% of the biological variation, varying according to the genotype. Maximum air temperature explained only 2.4% of the biological variation. This finding is in line with what was observed by Loro,[32] when evaluating the influence of meteorological variables on 26 white oat genotypes, where temperatures explained between 2 and 10% of the biological variation.

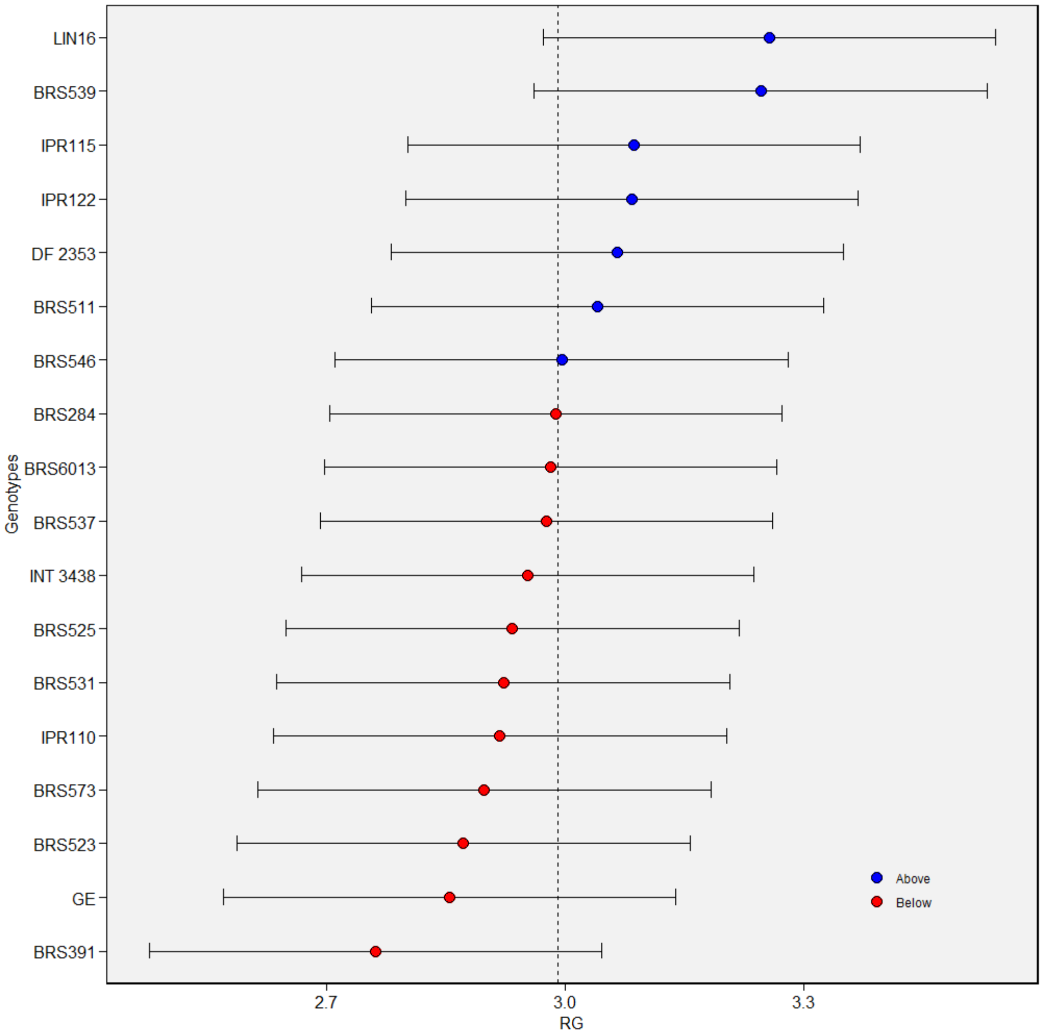

Figure 2. Best general linear unbiased predictor (BLUP) for the grain yield trait of eighteen soybean genotypes in 21 growing environments.

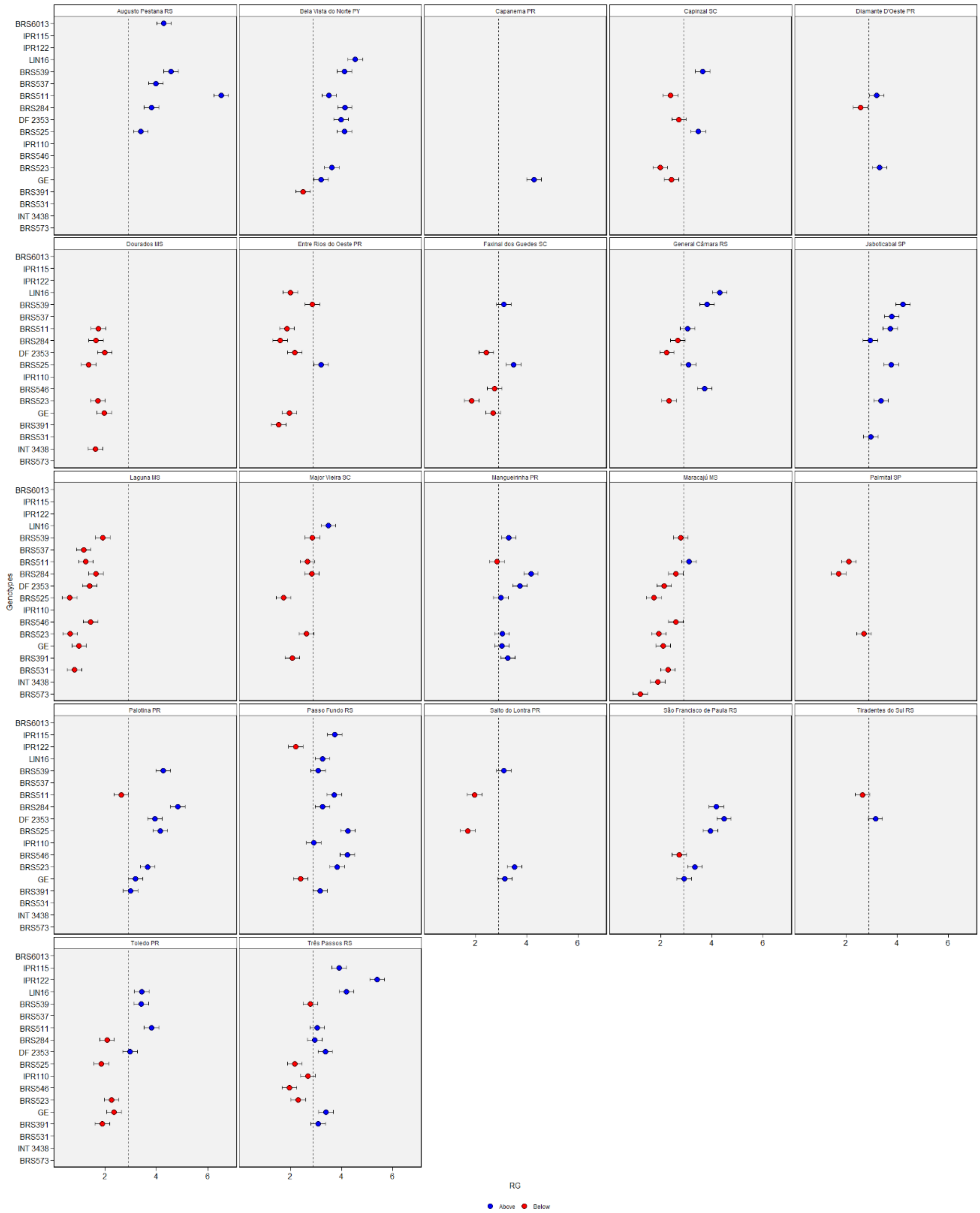

Figure 3. Estimation of productivity averages by stratified BLUP, measured in 18 genotypes and 21 environments in the years 2019/2020, 2020/2021 and 2021/2022.

According to the responsiveness of the genotypes to environmental and geographic factors (Figure 6), it was observed that the majority of genotypes showed positive responsiveness to longitude (LON), with the exception of BRS 284(G1), BRS 531 (G6), DF 2353(G12) and GE (G13), however for latitude (LAT) positive responsiveness occurred only for BRS 531 (G6), BRS 391 (G2) and BRS 546 (G9). It was inferred that for the factors minimum air temperature (Tmin), precipitation (Prec), radiation (RAD), soil clay content (CC), CTC and altitude (ALT), all genotypes had similar responsiveness. However, for the soil pH variable, all genotypes have high responsiveness.

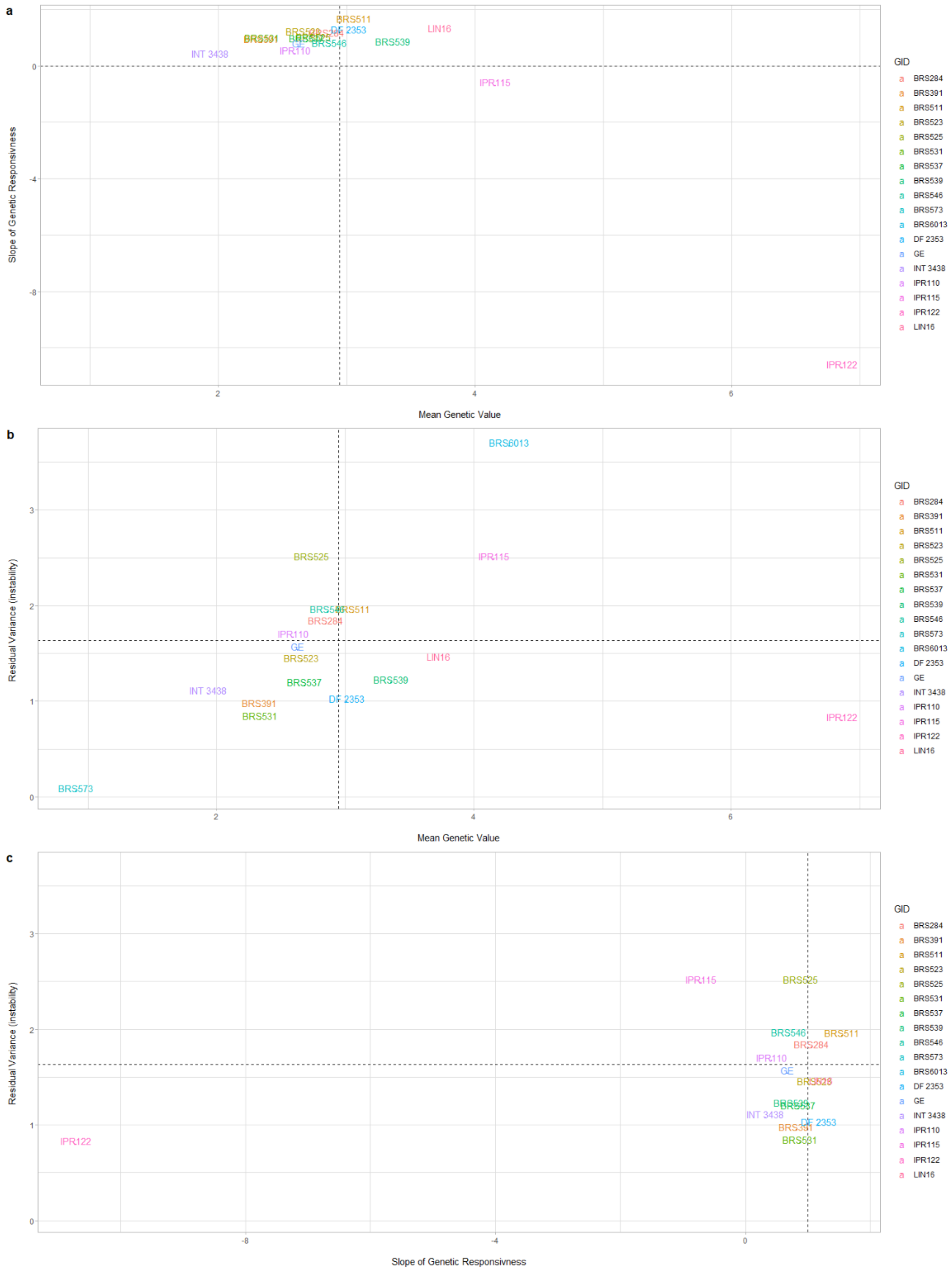

Figure 4. Reaction standard comparing the genetic average and stability of 18 conventional soybean genotypes in 21 growing environments in the 2019/2020, 2020/2021 and 2021/2022 harvests.

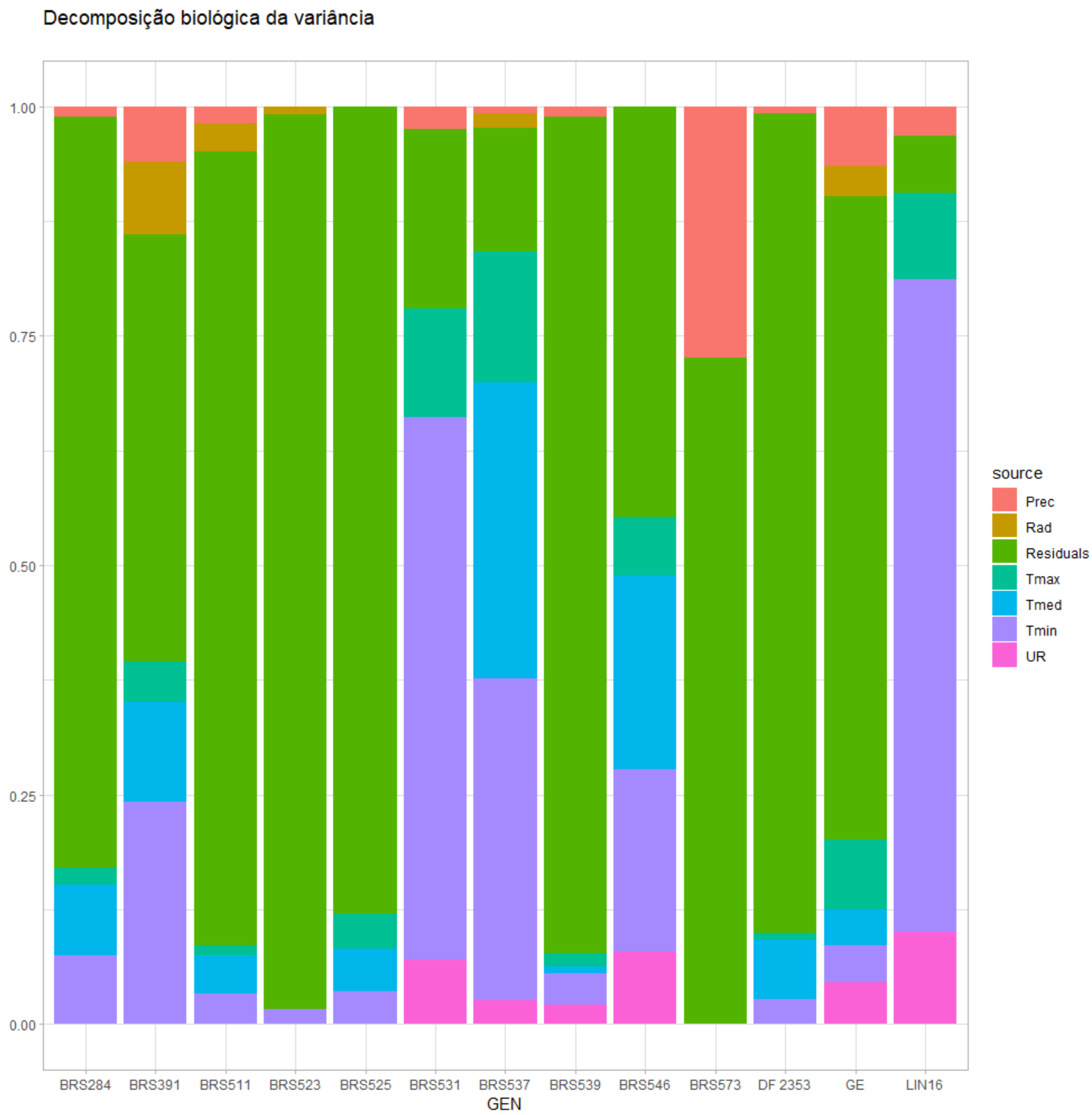

Figure 5. Biological decomposition of the interaction variance, highlighting the influence of each environmental and soil factor on the cultivars used in the study. Variables: RH: relative air humidity; Tmax: maximum air temperature; Tmed: mean air temperature; DS: soil density; Tmin: minimum air temperature; Rad: incident radiation; pH: soil hydrogen potential; CTC: soil cation exchange capacity; N: soil nitrogen content; DCO: soil organic carbon density; OCS: soil organic carbon stock; CC: soil clay content; Residuals: residue.

SCENARIO II PREDICTION FOR THE YEARS FROM 2023 TO 2040

For future scenarios, based on predictions from the National Institute for Space Research (INPE), for the variables minimum air temperature (Tmin), mean air temperature (Tmean), maximum air temperature (Tmax), relative air humidity (RH%), precipitation (Prec) and incident radiation (Rad), it is possible to understand the behavior of these meteorological variables in the 21 cultivation environments during the years 2023 to 2040.

According to the minimum air temperature predicted between 2023 and 2040, it was observed that lower temperatures will occur in São Francisco de Paula- RS, Passo Fundo- RS and Major Vieira- SC, with minimums between 13.26 ºC and 16.22 ºC. However, the highest minimum temperatures will occur in Bela Vista do Norte- PY, with minimums of 20.95 and 23.09 ºC. A similar trend is predicted for mean and maximum air temperatures, where São Francisco de Paula- RS, Passo Fundo- RS and Major Vieira- SC will present the lowest mean and maximum air temperatures, on the other hand, Bela Vista do Norte- PY, will occur higher temperatures.

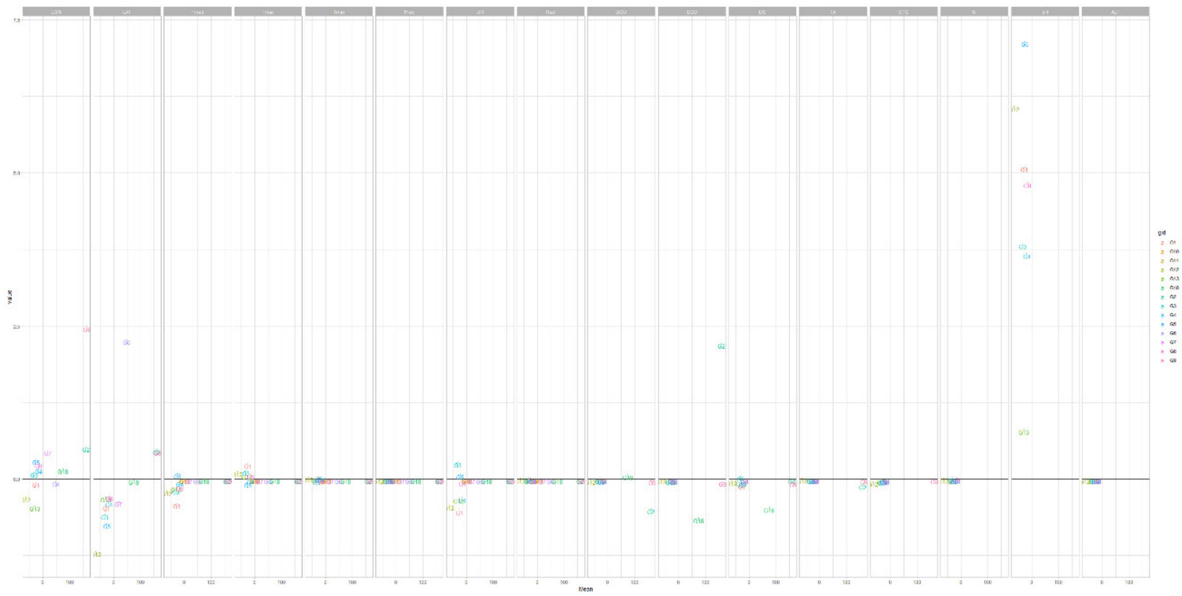

Figure 6. Responsiveness of the 18 conventional soybean genotypes with the variables analyzed. Variables: RH: relative air humidity; Tmax: maximum air temperature; Tmed: mean air temperature; DS: soil density; Tmin: minimum air temperature; Rad: incident radiation; pH: soil hydrogen potential; LAT: latitude; CTC: soil cation exchange capacity; N: soil nitrogen content; DCO: soil organic carbon density; OCS: soil organic carbon stock; CC: soil clay content; LON: longitude; ALT: altitude; Residuals: residue. Genotypes: G1: BRS 284; G2: BRS 391; G3: BRS 511; G4: BRS 523; G5: BRS 525; G6: BRS 531; G7: BRS 537; G8: BRS 539; G9: BRS 546; G10: BRS 573; G12: DF 2353; G13: GE; G18: LIN 16.

Furthermore, the year 2026 should present the highest minimum temperatures (14.43 ºC to 23.09 ºC), mean (20.19 ºC to 30.03 ºC) with predictions between 14.43 ºC and 23.09 ºC. According to Loro,[32] this occurs because temperatures are correlated with each other, therefore with an increase in the maximum air temperature, consequently there is a tendency for higher minimums and means. Alsajri,[33] report that soybean seed mass is negatively correlated with temperature, in addition to reducing its weight by 2.6% for every 1 ºC increase in temperature.

For the variable relative air humidity (%), in the year 2022, it is observed that the environments of General Câmara- RS, Major Vieira- SC, Passo Fundo- RS and São Francisco de Paula- RS recorded the highest values, with 78.78, 75.64, 71.4 and 73.3%. On the other hand, the driest environment for this year was Jaboticabal-SP, with 43.71%. In general, for most environments, it can be highlighted that the period 2023-2030 will present lower humidity than the decade 2030-2040. Between 2026 and 2027 it is clear that there will be a general decrease in humidity compared to previous years, for most environments.

The incident radiation predicted for the years 2023 to 2040, it was observed that there is a tendency for radiation to increase, especially from 2030 onwards. It was inferred that the environments of Bela Vista do Norte- PY and Maracaju- MS, will have the greatest increases in incident radiation values, these environments may have the grain quality affected, mainly the protein content, as according to Sobko,[34] the increase in solar radiation, especially during the flowering period, the protein content tends to be reduced. Precipitation, it is observed that the period between 2020 and 2030, will be characterized by low precipitation volumes, from 2030 onwards, there will be a tendency for rain volumes to increase. The environments Capinzal- SC, Mangueirinha- PR and Major Vieira- SC, show the highest accumulated precipitation.

Based on the analysis of main components of the trend of climatic variables with cultivation environments, it revealed that Diamante do Oeste- PR, Palotina- PR, Toledo-PR, Palmital- SP, Jaboticabal- SP, Maracaju- MS, Laguna - MS and Dourados- MS, showed greater predisposition to the variables mean and maximum air temperature. On the other hand, Entre Rios- PR had a greater affinity for radiation and minimum air temperature and a relationship can be made between these components, defining the magnitude of the interaction of each component with each environment.

The decomposition of environmental variability of variance represents the degree of influence of each predicted climate variable on the genotypes. It was observed that the genotypes LIN 16, BRS 531 and BRS 537 and BRS 391 suffer a high negative influence from the minimum air temperature, with a contribution of 71.15%, 59.19%, 32.30% and 24.22% respectively. For the BRS 537 genotype, precipitation should have a greater influence on the grain yield, with a contribution of 27.37%. Sobko,[34] report that periods of mild temperatures during the reproductive period, the protein content tends to be lower.

According to the prediction of the genetic responsiveness of the 18 genotypes with the meteorological variables for the period 2023 – 2040, it was observed that at the mean air temperature (Tmean), the highest positive responsivities are from the genotypes BRS 531 (G6), BRS 537 (G7) and BRS 546 (G9). However, for maximum temperature the most responsive genotypes were BRS 391 (G2), BRS 525 (G5) and GE (G13). At minimum temperature, only the BRS 525 (G5) genotype had a positive performance, while the others showed negative responses. In relation to precipitation, relative air humidity and incident radiation, all genotypes had similar behaviors, remaining close to zero, that is, without a tendency towards strong responsiveness either to the negative or positive side.

In this study, it was possible to observe that the BRS 391 and BRS 546 genotypes are responsive to soils with low clay content and organic matter content, and could form future breeding banks to obtain cultivars for soils with lower organic matter content. The GE genotype, which responded to a decrease in relative humidity (RH), could be useful for obtaining cultivars for drier environments.

Comparing with the results obtained in the years 2019/2020, 2020/2021 and 2021/2022, a change in performance was observed for all genotypes evaluated, where these analyzed variables presented distinct influences on the expression of their productivity. It was observed that the prediction for from 2023 onwards, the minimum temperature began to have a greater influence on the expression of soybean grain productivity.

CONCLUSION

The genotypes LIN 16, BRS 539 and IPR 115 are superior in terms of grain productivity. The BRS 511 genotype had a high genetic average, high responsiveness to improvements in the growing environment and high stability. In the current scenario, latitude, soil pH and soil organic carbon stock are determining factors for the grain yield of genotypes destined for organic management.

In the future scenario, the minimum, mean and maximum air temperatures will be the basis for positioning soybeans in organic conditions. The year 2026 will be the most critical for soybean production in southern Brazil due to low precipitation and high temperatures. In this context, it is envisaged to select cultivars that tolerate hot environments and are resilient to water restrictions. To guarantee their potential, it is necessary to provide environments with high fertility, vegetation cover and minimal interspecific competition with other plant species.

SUPPLEMENTARY MATERIAL

Supplementary data are available at: https://docs.google.com/document/d/1dIOUR1H-sAVexUYSh7gX2ND66Gq0_US2q/edit?usp=sharing&ouid=107947598540761207822&rtpof=true&sd=true

DATA AVAILABILITY

The entire dataset supporting the results of this study has been made available on Github and can be accessed at "https://github.com/IRC1000/Use-of-geographic-and-edaphoclimatic-information-for-the-selection-of-soybeans-".

AUTHOR CONTRIBUTIONS

Conceptualization: Rafael Wirzbicki Casarotto.

Data curation: Ivan Ricardo Carvalho.

Formal analysis: Ivan Ricardo Carvalho.

Investigation: Aljian Antonio Alban, Marcio Alberto Challiol, Rafael Wirzbicki Casarotto.

Methodology: Ivan Ricardo Carvalho, Rafael Wirzbicki Casarotto.

Supervision: João Pedro Dalla Roza, Leonardo Cesar Pradebon, Murilo Vieira Loro, Willyan Junior Adorian Bandeira.

Validation: Aljian Antonio Alban, Marcio Alberto Challiol.

Writing – review & editing: Deivid Araújo Magano, Ivan Ricardo Carvalho, José Antonio Gonzalez da Silva, Leonardo Cesar Pradebon, Rafael Wirzbicki Casarotto.

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