

Sowing Time and Plant Density Influence on some Productivity Parameters in Soybean (*Glycine max* (L.) Merr.)

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Abstract. The variation of some productivity parameters in soybean, 'IRIS TD' variety (ARDS Turda), was evaluated in relation to three sowing times (E I, E II, E III), and five row spacing - plane density variants (V1 - V5). The soybean crop was located within the ARDS Lovrin, in a non-irrigated system, on a field with chernozem soil. The experimental variants were placed randomly, in three repetitions. Six productivity parameters were determined at the plant and pod level: pod number per plant (PPN), pod length (PL), pod width (PW), pod shell weight (PSW), grain weight (GW), and soybean pod weight (SPW). The average values were analyzed, across the experimental variants. The results indicated a dominant effect of sowing date, with all traits increasing from E I (17.04.2025) to E III (12.05.2025). For the SPW parameter, the average increased from 4,343 g in the case of E I, to 5,900 g in the case of E II and 6,684 g in the case of E III. The effect of row spacing - plant density was much smaller than the effect of sowing time, and the highest SPW values were observed in E III × V2 (7,183 g) and E III × V3 (6,827 g). Pearson correlations revealed very strong relationships between SPW and PSW ($r = 0.976$), GW ($r = 0.970$), PW ($r = 0.948$), PPN ($r = 0.948$) and PL ($r = 0.935$). Principal component analysis showed that PC1 explained 95.18% of the total variance, clearly separating the sowing times on a productivity growth gradient.

Keywords: agronomic parameters, clustering, comparative analysis, correlations, PCA, plant density, sowing time, soybean

INTRODUCTION

Soybean (*Glycine max* (L.) Merr.) is one of the most important leguminous plants cultivated worldwide, due to its food, feed and industrial value (Lyu et al., 2023; Rotundo et al., 2024; Gai et al., 2025). The high protein and oil content gives this species a strategic role in modern agriculture, and interest in expanding cultivated areas is constantly growing (Guo et al., 2022; Baisch et al., 2024). In the context of climate change and the need to develop sustainable agricultural systems, the adaptability of genetic material and the optimization of soybean cultivation technology have become major research directions (Kakati et al., 2024; Zhao et al., 2025; Lv et al., 2026; Nawaz et al., 2026). Among the technological stages with a direct impact on the level and stability of production, the sowing time and plant density occupy a central place, as they influence both the vegetative development and the reproductive processes of the crop (Fordoński et al., 2023; Moseley et al., 2025; Safina et al., 2025).

Determining the sowing time is one of the most important technological decisions in soybean, as it synchronizes emergence, vegetative growth, flowering, pod formation and grain filling with the local temperature regime, solar radiation and water availability. The sowing date, correlated with the biological requirements of the crop plant, influences emergence, the duration of each phenological phase and can significantly modify the productive potential of the crop. Numerous researches have demonstrated that changing the sowing time determines changes in the growth rate, biomass accumulation and the formation of production components, the effects being dependent on the genetic particularities of the cultivar, the maturity group and the climatic conditions specific to each agricultural year (Bastidas et al., 2008; Bateman et al., 2020).

The importance of sowing time is amplified by the fact that it directly influences the relationship between the plant and environmental factors throughout the growing season. Soil temperatures at the time of sowing determine the emergence and uniformity of the crop, while the positioning of reproductive phases at certain times of the season can favor or limit the process of pod and seed formation. In this regard, it has been demonstrated that changes in sowing date can affect both the number of pods per plant, seed mass and the efficiency of environmental resource use (Hu and Wiatrak, 2012; Kessler et al., 2020).

In regions with a temperate-continental climate, choosing the optimal sowing time often represents a compromise between the advantages and risks associated with each period. Sowing too early can expose seeds and young plants to low temperatures, slowing germination and promoting uneven emergence. Conversely, excessive delay in sowing can shorten the length of the growing season and shift critical phases of the crop to periods of high temperatures and water deficit. For this reason, the specialized literature reports different results depending on the climatic conditions of each year and study locations, with situations in which early sowing

avored obtaining higher yields, but also cases in which intermediate or later times offered the best results (Egli and Bruening, 2006; Jarecki and Bobrecka-Jamro, 2021). In recent years, amid the increasing frequency of extreme weather events, the interest of researchers and farmers has increasingly focused on identifying optimal sowing times adapted to local conditions. Recent studies have highlighted that crop response to sowing date cannot be generalized, being influenced by the complex interaction between temperature, precipitation, photoperiodism and the genetic characteristics of the cultivated varieties (Książak and Bojarszczuk, 2022; Staniak et al., 2023).

Another essential technological link for soybean crop performance is row spacing and plant density (Thompson et al., 2015). The spatial distribution of plants determines the level of intra-specific competition for light, water and nutrients, influencing the development of the foliar apparatus and the photosynthetic efficiency of the crop. High densities favor faster row closure and increased capacity to intercept solar radiation, but can intensify competition between plants, reducing individual development and branching capacity (De Bruin & Pedersen, 2008b; Carciochi et al., 2019).

In contrast, lower densities allow for the development of a greater number of branches and biological compensation by increasing the number of pods per plant. The ability of soybean to compensate for density variations is well known and is one of the reasons why this species exhibits high ecological plasticity. However, the limits of this compensation capacity depend on environmental conditions and the technology applied (Lee et al., 2008; Gaspar et al., 2020).

In addition to the individual effects of the two factors, the literature emphasizes the importance of the interaction between sowing time and plant density. Under late sowing conditions, reducing the duration of the vegetative period can limit branch development and pod formation, which is why higher densities are often recommended to compensate for these effects. In contrast, in the case of early sowing, plants benefit from a longer growth period and can more effectively compensate for reduced densities by developing additional reproductive organs through branching (De Bruin and Pedersen, 2008a; Nleya et al., 2020). Numerous recent studies have confirmed that simultaneous optimization of sowing time and density can lead to improved resource efficiency and increased production stability. However, the relationship between the two factors is strongly dependent on local growing conditions, which justifies the need for regional and local studies through field experiments (Schmitz and Kandel, 2021; Siler and Singh, 2023). Similar results have been reported in other soybean growing areas, where the density response changed depending on the sowing date and climatic conditions during the growing season (Umburanas et al., 2019).

In Central and Eastern Europe, including regions with pedoclimatic characteristics close to those of the Western Plain of Romania, recent research has highlighted the need to adapt crop technology to the particularities of each agricultural year. The choice of sowing time must be made according to soil temperature, water reserve and the duration of the vegetation period, and the optimal density must be correlated with the maturity group and branching capacity of the cultivated variety (Borowska and Prusiński, 2021). Also, studies conducted in Poland and other countries in the region have demonstrated that the crop's reaction to the sowing date can vary significantly from one year to another, depending on the thermal and rainfall regime (Serafin-Andrzejewska et al., 2024).

To understand the mechanisms through which technological factors influence production, a detailed analysis of productivity components is necessary. Parameters such as the number of pods per plant, pod size, husk mass and grain mass provide valuable information on how plants respond to growing conditions and transform available resources into production (He et al., 2023; Jia et al., 2025). The evaluation of these characters allows the identification of physiological and morphological links that contribute to the differentiation of experimental treatments and facilitates the generation of models for the evaluation of yields (Lu et al., 2022; Mathew et al., 2023; Jia et al., 2025).

Physiological and agronomic studies have shown that final soybean production is closely related to the number of seeds formed and their mass, and the relationships between production components can explain a large part of the yield variation. The plant's ability to form and maintain a high number of pods, as well as the efficiency of the grain filling process, are essential elements for achieving high and stable yields (Board and Harville, 1996; Moreira et al., 2015). At the same time, productive performance is influenced by the canopy's capacity to support photosynthetic activity and the efficient distribution of assimilates to the reproductive organs (Robinson et al., 2009; Umburanas et al., 2019).

In this context, the objective of this research was to evaluate the effect of sowing time, density variants and the interaction between these factors on the main productivity parameters of the 'IRIS TD' soybean variety (ARDS Turda), cultivated under the specific pedoclimatic conditions of SCDA Lovrin in 2025. The study also aimed to identify the relationships between the analyzed characters through Pearson correlations and principal component analysis (PCA), in order to highlight the parameters with a determining role in differentiating the experimental treatments and explaining the observed biological variability.

MATERIAL AND METHODS

Study location and experimental conditions

The experiment was carried out in the agricultural year 2024 – 2025 at the Agricultural Research and Development Station Lovrin (ARDS Lovrin), Timiș County, Romania. The climatic conditions during the field experiments are presented in Table 1, based on the records of climatic parameters at the ARDS Lovrin Weather Station.

Table 1. Climatic conditions at the study location

Month/Decade 2025	Average air temperature (°C)	Sum of temperature (°C)	Average relative air humidity (%)	Precipitation (mm)
April/I	7.4	76.9	67	1.8
April/II	14.7	138.6	64	12.2
April/III	17.1	202.1	66	8.8
Monthly average/amount	13.8	-	66	22.8
May/I	16.3	163.0	66	25.2
May/II	12.9	129.2	66	20.0
May/III	16.3	179.2	75	22.0
Monthly average/amount	15.2	-	69	67.2
June/I	23.4	234.5	48	15.2
June/II	22.5	226	61	8.2
June/III	25.0	295.8	56	30.0
Monthly average/amount	25.0	-	55	53.4
July/I	23.9	238.64	48	15.2
July/II	22.5	223.6	61	8.2
July/III	25.2	350.3	56	30.0
Monthly average/amount	23.9	-	55	53.4
August/I	23.9	230.6	44	0.0
August/II	25.6	256.3	42	3.0
August/III	21.4	284.7	51	18.6
Monthly average/amount	23.6	-	48	29.4
September/I	24.0	179.9	44	4.6
September/II	19.9	139.2	68	20.4

Study location condition

The soybean crop was located under non-irrigated conditions, on a uniform terrain in terms of land morphology, characterized by chernozem soil, with medium - high natural fertility, conditions specific to the Western Plain of Romania, Figure 1.

Biological material and experimental variants

The biological material used in the experiment was represented by the soybean variety 'IRIS TD' (ARDS Turda), cultivated with a technology specific to the area.

The experiment was organized according to a bifactorial model, with two experimental factors:

- ❖ Factor A – sowing season (E), with three levels: E I – April 17, 2025; E II – April 28, 2025; E III – May 12, 2025;
- ❖ Factor B – plant density and row spacing, with five variants: V1 – 45 plants m⁻² at 25 cm between rows; V2 – 55 plants m⁻² at 25 cm between rows; V3 – 65 plants m⁻² at 25 cm between rows; V4 – 45 plants m⁻² at 60 cm between rows; V5 – 45 plants m⁻² at 80 cm between rows. For each experimental variant, three repetitions were provided, and the values used in the analysis of this study represent the averages of the three repetitions.

In order to characterize the biological response of plants to experimental factors, six productivity parameters were determined at the pod and seed level: PPN (Pods per Plant Number); PL (Pod Length, cm); PW (Pod Width, cm); PSW (Pods Shell Weight, g); GW (Grains Weight, g); SPW (Soybean Pod Weight, g).

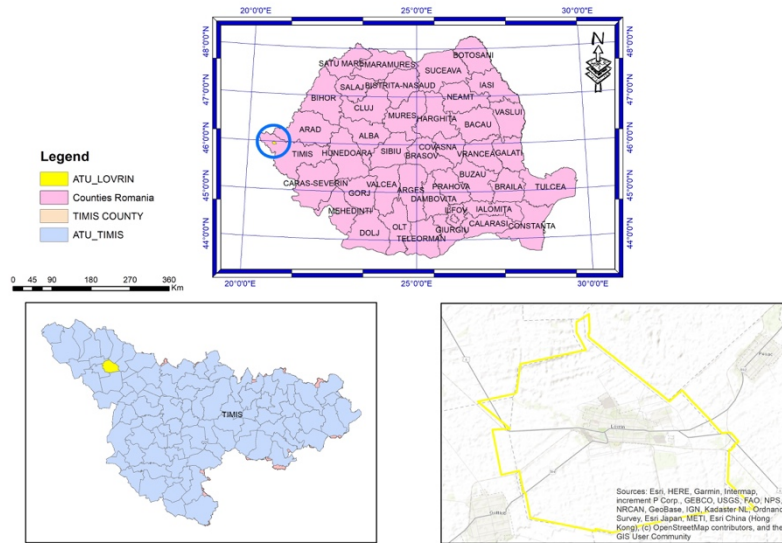


Figure 1. Study location

Statistical analysis of data

To evaluate the effects of the experimental factors, the bifactorial model, Equation (1), was used.

$$Y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + \varepsilon_{ijk} \quad (1)$$

where:

Y_{ijk} – observed value for the analyzed character;

μ – general average;

A_i – the effect of the sowing season;

B_j – the effect of density variant;

$(AB)_{ij}$ – the interaction effect of the two factors;

ε_{ijk} – experimental error

Statistical analysis was performed based on experimental means. Relationships between productivity parameters were evaluated using the Pearson correlation coefficient. Correlation matrices and heatmaps were constructed to interpret the relationships between characters, which allow highlighting the degree of association between the analyzed parameters. To investigate the multivariate structure of the data and identify the main sources of variation, Principal Component Analysis (PCA) was applied. Before performing PCA, the data were standardized according to Equation (2).

$$Z_{ij} = \frac{x_{ij} - \bar{x}_j}{s_j} \quad (2)$$

where:

Z_{ij} – standardized value;

x_{ij} – initial value;

$\bar{x}_j$ – mean of the variable;

s_j – standard deviation.

The principal components were extracted by diagonalizing the correlation matrix, Equation (3).

$$|R - \lambda I| = 0 \quad (3)$$

where:

R – correlation matrix;

λ – eigenvalues;

I – identity matrix.

The percentage of variation explained by each principal component was calculated using Equation (4).

$$PV_i = \frac{\lambda_i}{\sum_{j=1}^p \lambda_j} \times 100 \quad (4)$$

PCA analysis was used to highlight the relationships between productivity traits and to identify clusters determined by sowing time and plant density. The calculation module in EXCEL, the PAST v.4.14 software (Hammer et al., 2001), the JASP v.0.16.2 software (2022) were used for data analysis and graph generation.

RESULTS AND DISCUSSIONS

The effect of sowing times

Sowing time had the clearest effect on the analyzed parameters. All six parameters increased progressively from E I to E III. For PPN, the increase was from 11.237 pods plant⁻¹ at E I to 16.847 pods plant⁻¹ at E III. For SPW, the increase was from 4.343 g to 6.684 g, Table 2, Figure 2. This trend shows that, under the conditions of 2025 in Lovrin, the sowing on May 12 best coincided with the conditions for growth and pod formation.

Table 2. Average parameters according to sowing time (E)

Sowing season	PPN (no)	PL (cm)	PW (cm)	PSW	GW (g)	SPW
E I	11.237	2.951	0.704	1.731	2.435	4.343
E II	14.080	3.309	0.799	2.695	3.203	5.900
E III	16.847	3.774	0.907	2.918	3.733	6.684

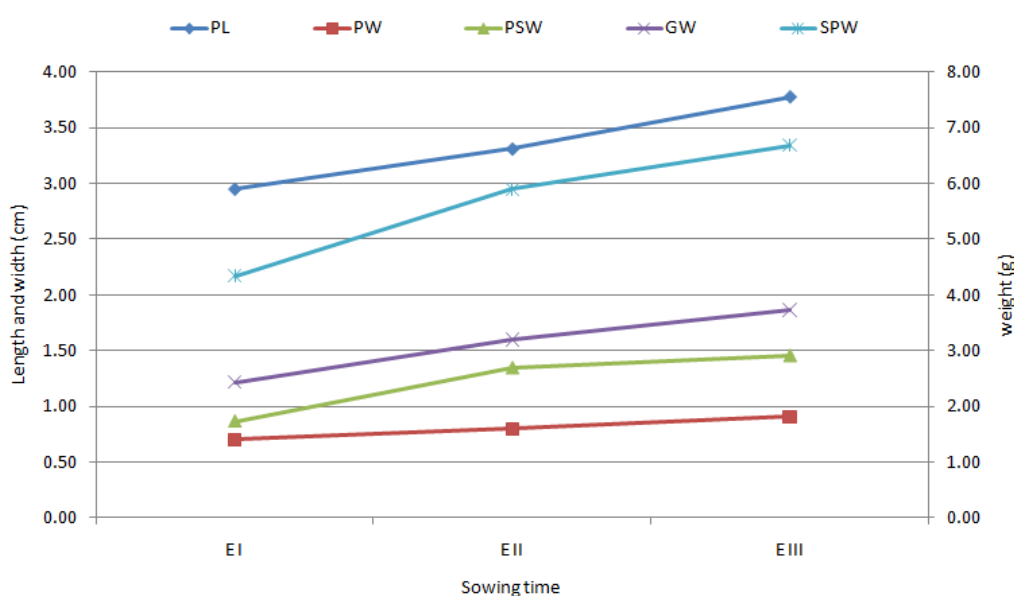


Figure 2. Dynamics of productivity parameters depending on the sowing season

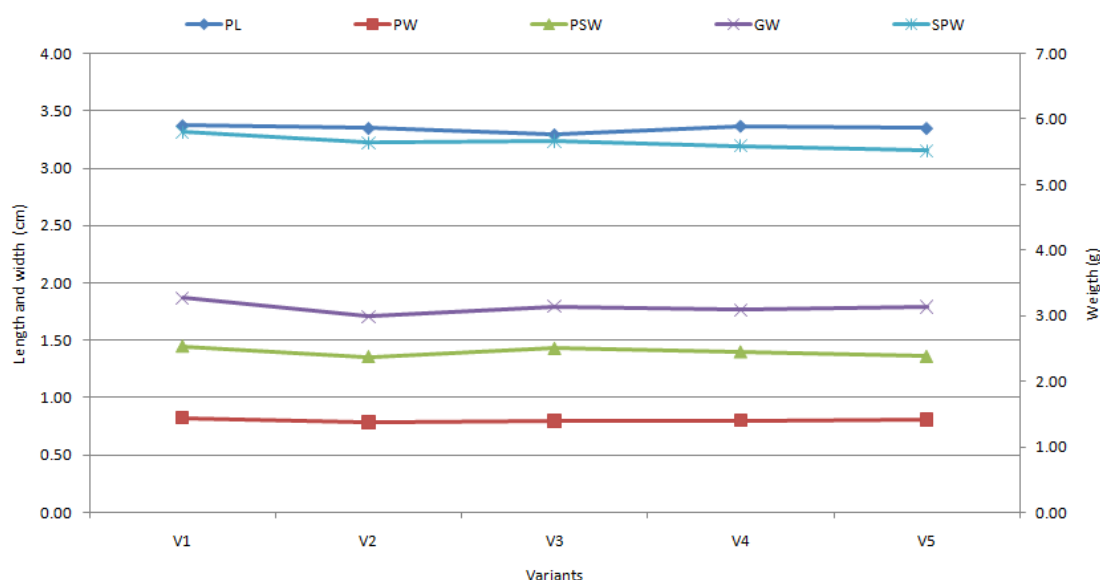
The result is particular to numerous studies that frequently indicate the advantage of early sowing; the difference can be explained by the local nature of soil temperature, precipitation and crop establishment in the experimental year (Hu and Wiatrak, 2012; Bateman et al., 2020; Jarecki and Bobrecka-Jamro, 2021; Serafin-Andrzejewska et al., 2024).

The effect of density variants

The differences between density variants were smaller than the differences between epochs. Variant V1 presented the highest mean values for PPN, PL and SPW parameters, while variant V2 had the highest mean value for GW, only in combination with sowing epoch E III. At the general mean level across epochs, SPW varied within a narrow range, from 5.517 g in variant V5, to 5.803 g in variant V1, Table 3, Figure 3.

Table 3. Average parameters according to density/row spacing variant

Variant	PPN (no)	PL (cm)	PW (ccm)	PSW	GW (g)	SPW
V1	14.722	3.371	0.824	2.537	3.267	5.803
V2	13.989	3.348	0.787	2.374	2.989	5.637
V3	13.429	3.290	0.798	2.503	3.141	5.667
V4	13.878	3.367	0.801	2.448	3.086	5.589
V5	14.256	3.348	0.807	2.377	3.137	5.517

**Figure 3.** Dynamics of productivity parameters depending on the variants associated with plant density

This plasticity is characteristic of soybean, a species that can partially compensate for different densities through branching, number of pods and distribution of assimilates (De Bruin and Pedersen, 2008b; Lee et al., 2008; Carciochi et al., 2019; Gaspar et al., 2020).

ANOVA test on means

The ANOVA test applied to the means indicated very strong effects of sowing time for all parameters. The F values for time were very high, from 30.746 for GW to 148.600 for PW, and the p values indicated statistical certainty.

In contrast, the effect of plant density and row spacing variants was not significant for any parameter in this approach on the means, with p values ranging from 0.251 to 0.881 ($p > 0.05$). The agronomic interpretation is that, under the study conditions, specific to the year 2025, the sowing calendar was the main determinant of the differentiation of the characters, and density had a secondary role.

Table 3. Two-way ANOVA for main effects.

Parameter	F_Ep	p_Ep	F_Var	p_Var
PPN	84.360	0.000	1.469	0.298
PL	122.924	0.000	0.454	0.768
PW	148.600	0.000	1.659	0.251
PSW	76.909	0.000	0.621	0.660
GW	30.746	0.000	0.439	0.777
SPW	59.305	0.000	0.283	0.881

For the interaction of factors (sowing season $\times$ plant density variant), a descriptive representation was generated for the SPW parameter, through 3D surfaces, Figure 4, and interaction deviations from the additive model, Figure 5. The most favorable combinations for SPW were E III $\times$ V2 and E III $\times$ V3, which suggested that densities of 55–65 plants m^{-2} at 25 cm between rows best utilized the third season (E III).

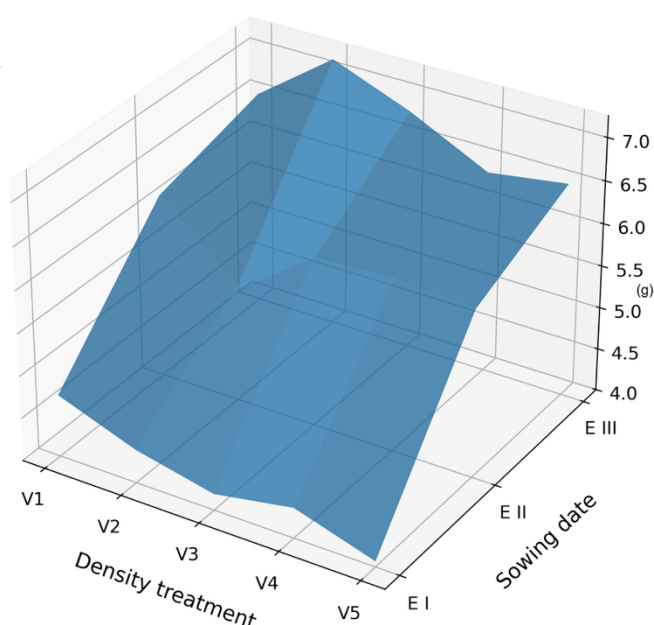


Figure 4. 3D representation of SPW response to epoch $\times$ variant combinations

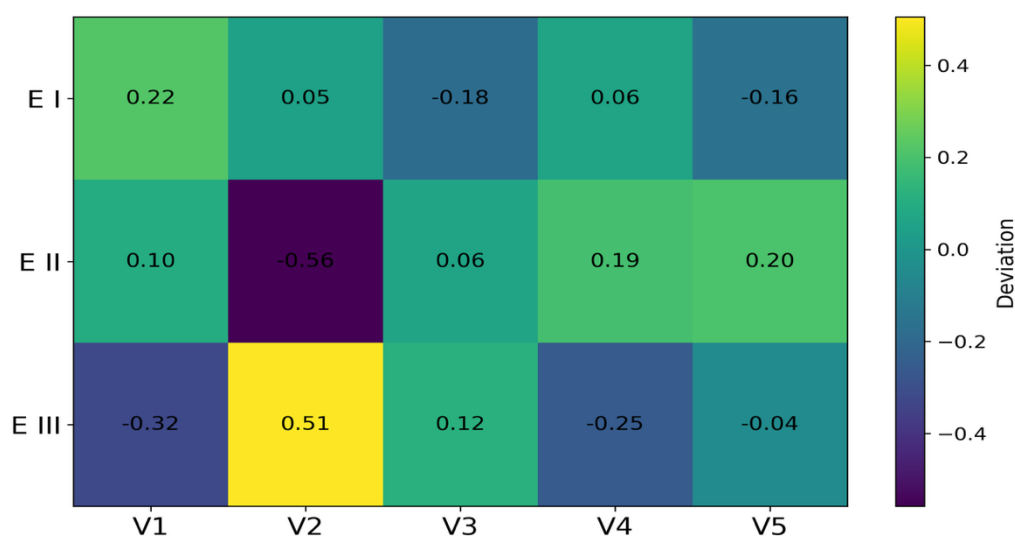


Figure 5. Descriptive interaction deviations for SPW

Correlations and interdependence matrix

The correlation matrix showed very strong interdependence between all productivity traits considered, Figure 6. SPW was very strongly positively correlated with PSW ($r = 0.976$) and GW ($r = 0.970$), which is logical because the total pod mass includes the structural contribution of the shell and the productive contribution of the grains. High correlations were also observed between PPN, PL, PW and SPW, indicating that plants with more pods and with more morphometrically developed pods tend to present higher mass values.

The relationship between pod architecture parameters and grain weight confirms the role of production components in explaining soybean yield (Board and Harville, 1996; Robinson et al., 2009; Moreira et al., 2015; Borowska and Prusiński, 2021).

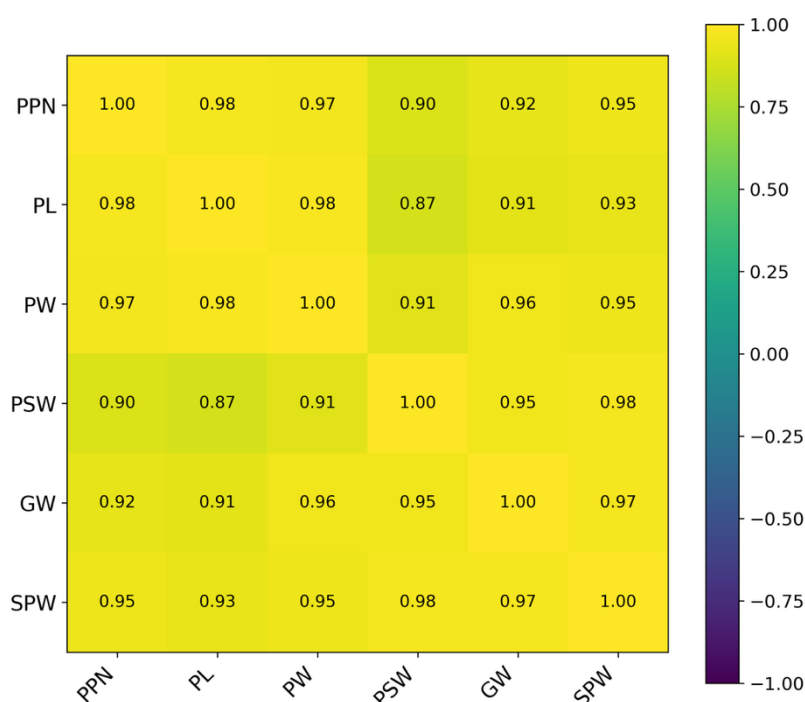


Figure 6. Graphical matrix of Pearson correlations

Multivariate analysis

Principal component analysis revealed a very clear multivariate structure, Figure 7. The first principal component explained 95.18% of the total variability, and the second component explained 3.14% of the total variance. PC1 was a general productivity gradient, positively loaded by all parameters, which separated the treatments in E I from those in E III. PC2 had a secondary role and differentiated mainly the ratio between weight and morphometric parameters. Clustering of points by epochs confirmed that the sowing epoch was the dominant factor in the multivariate configuration of the data.

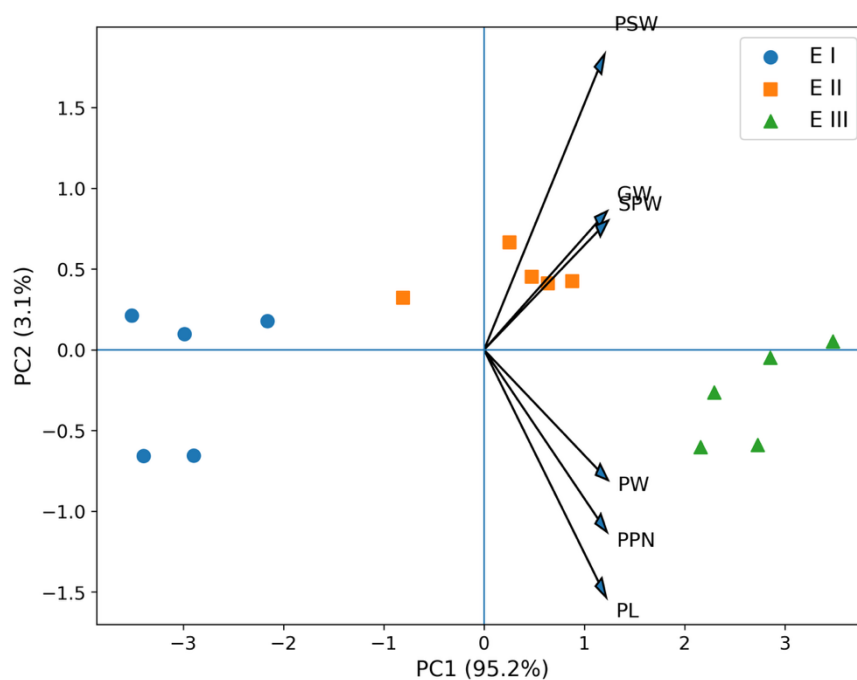


Figure 7. PCA biplot for the six determined characters

CONCLUSIONS

The sowing season had a major influence on all six productivity parameters analyzed in the soybean variety 'IRIS TD' (ARDS TURDA) under the specific cultivation conditions in the ARDS Lovrin area, agricultural year 2024 - 2025.

Sowing season E III, with sowing on 12.05.2025, determined the highest averages for PPN, PL, PW, PSW, GW and SPW.

Density variants (row spacing, plant density) had smaller effects than sowing times; at a descriptive level, V1 had the highest mean SPW, but the combinations E III $\times$ V2 and E III $\times$ V3 were the best performing in terms of points.

The very strong correlation between SPW and PSW, respectively GW, indicated that shell mass and grain mass were the main predictors of soybean pod mass.

Multivariate analysis (PCA) confirmed the dominance of sowing date in separating treatments, with PC1 explaining over 95% of the total variability.

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