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PRODUCTIVITY AND QUALITY OF SOYBEAN GRAINS GROWN UNDER DIFFERENT COVER PLANTS

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ABSTRACT - Soy is the main commodity in Brazilian agriculture, however its cultivation faces a series of challenges, such as pests, diseases, soil nutritional imbalance and other factors. The objective of this work was to verify the influence of different previous cultures on the productivity and nutritional quality of soybean grains. The experiment took place in the city of Pejuçara, in the state of Rio Grande do Sul - Brazil, in the 2019/20 agricultural season. The experiment took place in a 5X4 factorial scheme, in a randomized block design with four replications. The treatments composing by the combination of five soybean genotypes (BMX Lança IPRO, M 5838 IPRO, BMX Raio IPRO, BMX Zeus IPRO, DM57i52 IPRO), and four previous coverages. We measured morphological, productive and physicochemical characters of soybean grains. The data obtained were submitted to a density analysis, after which Pearson's linear correlation was performed in order to show the linear trend of association between the characters. Subsequently, Principal Component Analysis was performed to assess the interaction between the variables studied and the treatments. Moreover, cluster analysis to verify the levels of similarity that group the treatments. It is not possible to perceive a significant effect between the variables analyzed and the predecessor cultures used, in addition to the fact that in relation to bromatological quality, plant chemistry, productivity and nutritional quality of the grains, they presented values consistent with the literature. Thus, conclusion is that both predecessor cultures (oat, pasture, wheat and linseed) did not interfere directly in the soybean crop.
Keywords: *Glycine max* L., bioactive compounds, main components.

PRODUTIVIDADE E QUALIDADE DE GRÃOS DA SOJA CULTIVADA SOB DIFERENTES PLANTAS DE COBERTURA

RESUMO - A soja é a principal commodity da agricultura brasileira, contudo seu cultivo encara uma série de desafios, como pragas, doenças, desiquilíbrio nutricional do solo ente outros fatores. Para amenizar os problemas do cultivo desta oleaginosa, surge a possibilidade da utilização de espécies de inverno que possibilita a quebra de ciclo de pragas e doenças, bem como a ciclagem de nutrientes e a melhora das características físicas, químicas e biológicas do solo. O objetivo deste trabalho foi verificar a influência de diferentes culturas antecessoras na produtividade e qualidade nutricional de grãos da soja. O experimento foi realizado no município de Pejuçara, no estado do Rio Grande do Sul - Brasil, na safra agrícola 2019/20. O experimento ocorreu em esquema fatorial 5 x 4, em delineamento de blocos casualizados com quatro repetições. Os tratamentos foram compostos pela combinação de cinco genótipos da soja (BMX Lança IPRO, M 5838 IPRO, BMX Raio IPRO, BMX Zeus IPRO, DM57i52 IPRO), e quatro coberturas antecessoras. Foram mensurados caracteres morfológicos, produtivos e físico-químico dos grãos da soja. Os dados obtidos foram submetidos a uma análise de densidade, após a qual foi realizada a correlação linear de Pearson para mostrar a tendência linear de associação entre os caracteres. Posteriormente, foi realizada a Análise de Componentes Principais para avaliar a interação entre as variáveis estudadas e os tratamentos. Não é possível perceber efeito significativo entre as variáveis analisadas e as culturas predecessoras utilizadas, além do fato de que em relação à qualidade bromatológica, química da planta, produtividade e qualidade nutricional dos grãos, apresentaram valores condizentes com a literatura. As culturas antecessoras (aveia, pastagem, trigo e linhaça) não interferiram diretamente na composição físico-química da cultura da soja.
Palavras-chaves: *Glycine max* L., compostos bioativos, componentes principais.

INTRODUCTION

Soybean plays a fundamental role in the economy of the country, being the main commodity in Brazilian agriculture and the source of income for thousands of farmers. With a production of 135,911.7 thousand tons in the 2020/2021 crop, it presented an increase of 8.9% compared to the previous crop, with this, Brazil becomes the leader in the production and export of the oilseed in the world (CONAB, 2021).

In Rio Grande do Sul, the crop has become the main species cultivated in the summer crop, with an area of approximately 11,6 million hectares, representing 68,8% of the area of temporary and permanent crops (MARTIN et al., 2022). Thus, due to the vast area occupied, the large-scale

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appearance of diseases and pests, loss of biodiversity and nutritional imbalance in the soil, loss of productivity and higher production costs caused by monoculture requires consideration (OTÁVIO et al., 2021).

In order to ease such problems and maintain soybean productivity at low costs, there is the possibility of succession of different species in the winter crop, which make it possible to break the cycle of pests, diseases and weeds, as well as increase the soil biomass, nutrient cycling, soil biodiversity and physical and chemical characteristics (PACHECO et al., 2017).

In addition, the use of cover crops in the winter period is a viable method to circumvent the effects of soil compaction, as well as reduce erosion problems at different levels (DEBIASI et al., 2010). That can directly affect the final quality of the soybean grain, a very relevant parameter for commercialization and processing, which can affect the final value of the product. Among the main species cultivated in the crops of the state are wheat, oats, canola and barley, and there are still large areas for pasture that serve as cover and protection for the soil.

Understanding the main benefits brought by the cover species implanted during the period that precedes the soybean sowing presents on the production system, perceive the fundamental importance of the succession of different cultures for productivity and quality in agricultural production (FRANCHINI et al., 2009). However, the real effect that the prior species can cause on the yield productivity, nutritional components of the soybean crop is not known, requiring studies on the subject. Based on this, the objective of this study was to verify the influence of different previous cultures on the productivity and nutritional quality of soybean grains.

MATERIAL AND METHODS

The experiment took place in the city of Pejuçara, in the state of Rio Grande do Sul - Brazil, in the 2019/20 agricultural season. Soil characterized as Typical Dystroferric Red Latosol, and climate as humid subtropical (Koppel-Geiger climate classification: *Cfa*) (KÖPPEN, 1936).

The experiment took place in a 5x4 factorial scheme, in a randomized block design with four replications. The treatments composing by the combination of five soybean genotypes (BMX Lança IPRO, M 5838 IPRO, BMX Raio IPRO, BMX Zeus IPRO, DM57i52 IPRO), and four previous coverages (linseed, oat, wheat and pasture). Genotypes chosen according to their adaptability in the growing area in the region.

Sowing carried out mechanically, in the first half of November, at a density of 266,666 plants ha^{-1}, with a spacing of 0.45 m and 12 viable plants per linear meter, base fertilization in winter of 300 kg ha^{-1} of NPK, in the formulation of 11-52-00, and 130 kg of potassium chloride broadcast in the form of cover after sowing the soybean. Phytosanitary managements to control invasive plants, insect pests and diseases carried out in order to minimize the biotic effects on the result of this experiment.

The characters measured were: total protein, acid detergent fiber neutral detergent fiber, oil, mineral material, lignin, carbohydrates, calcium, phosphorus, potassium, magnesium, sulfur, height of insertion of the first legume (cm), plant height (cm), number of branches per plant, number of legumes on the main stem, number of legumes on branches number of legumes containing only one seed, number of legumes containing two seeds, number of legumes containing three seeds, number of legumes containing four seeds, grains weight per plant (g), number of legumes per plant, grains per plant, thousand grain weight (g), grain yield (kg), percentage of green grains (%), total grain protein, grain oil, crude fiber, grain mineral material, grain palmitic fatty acid, grain stearic acid, grain oleic fatty acid, grain linoleic acid and grain linolenic fatty acid.

The data obtained were submitted to a density analysis, after which Pearson's linear correlation was performed in order to show the linear trend of association between the characters (CARVALHO et al., 2004). Subsequently, Principal Component Analysis (PCA – Biplot) was performed to assess the interaction between the variables studied and the treatments (GOWER; HAND, 1996). Moreover, cluster analysis to verify the levels of similarity that group the treatments. Analyzes were performed using the statistical software GENES (CRUZ, 2013).

RESULTS AND DISCUSSION

Productivity components divides into two classes: the primary ones, which include the number of legumes/plants, number of grains/legumes and grain weight, which directly affect productivity. However, the secondary components indirectly affect the primary components, which are plant height, height of insertion of the first legume, final number of nodes and number of branches (CARVALHO et al., 2017).

Examining the density graphs among the 36 characters analyzed, made with 5 soybean varieties, and 4 previous coverings, the following results can be observed: in Figure 1, the insertion of the first legume (Figure 1a) was around 20 cm and the plant height (Figure 1b) measured from 75 to 80 cm, presenting a productivity zone of 55 to 60 cm. What, according to Sediyama et al. (2015), is within the parameters of soybean cultivars that have the highest yields, according to the same, IFL should be between 10 and 15 cm and PH between 50 and 90 cm. The number of branches (Figure 1c) was approximately one per plant with 10 legumes per branch (Figure 1e), on the other hand, on the main stem (Figure 1d) it presented two peaks, one with 25 legumes and the other with 35 legumes. The number of branches is a secondary component in the composition of grain yield, since the more NB the greater the number of reproductive nodes. However, this component suffers great pressure from the environment and management, depending a lot on the spacing and seeding density (SEDIYAMA et al., 2015).

The formation, fixation and development of legumes in soybean determine the total number of legumes per area, which is the most malleable component in the composition of productivity (THOMAS; COSTA, 2010). The total number of legumes per plant (Figure 1k) was, on average, 35 legumes, with approximately 2 to 3 legumes with 1 grain (Figure 1f), 15 to 17 legumes with 2 grains (Figure 1g), 20 legumes with 3 grains (Figure 1h) and 0.1 to 0.3 legumes with 4 grains (Figure 1i). The number of legumes is one of the most stable components among the other components, due to the uniformity promoted by genetic improvement (THOMAS; MUNDSTOCK, 2005). Regarding the number of grains per plant (Figure 1j) it was between 90 grains with a grain weight per plant around 14 g.

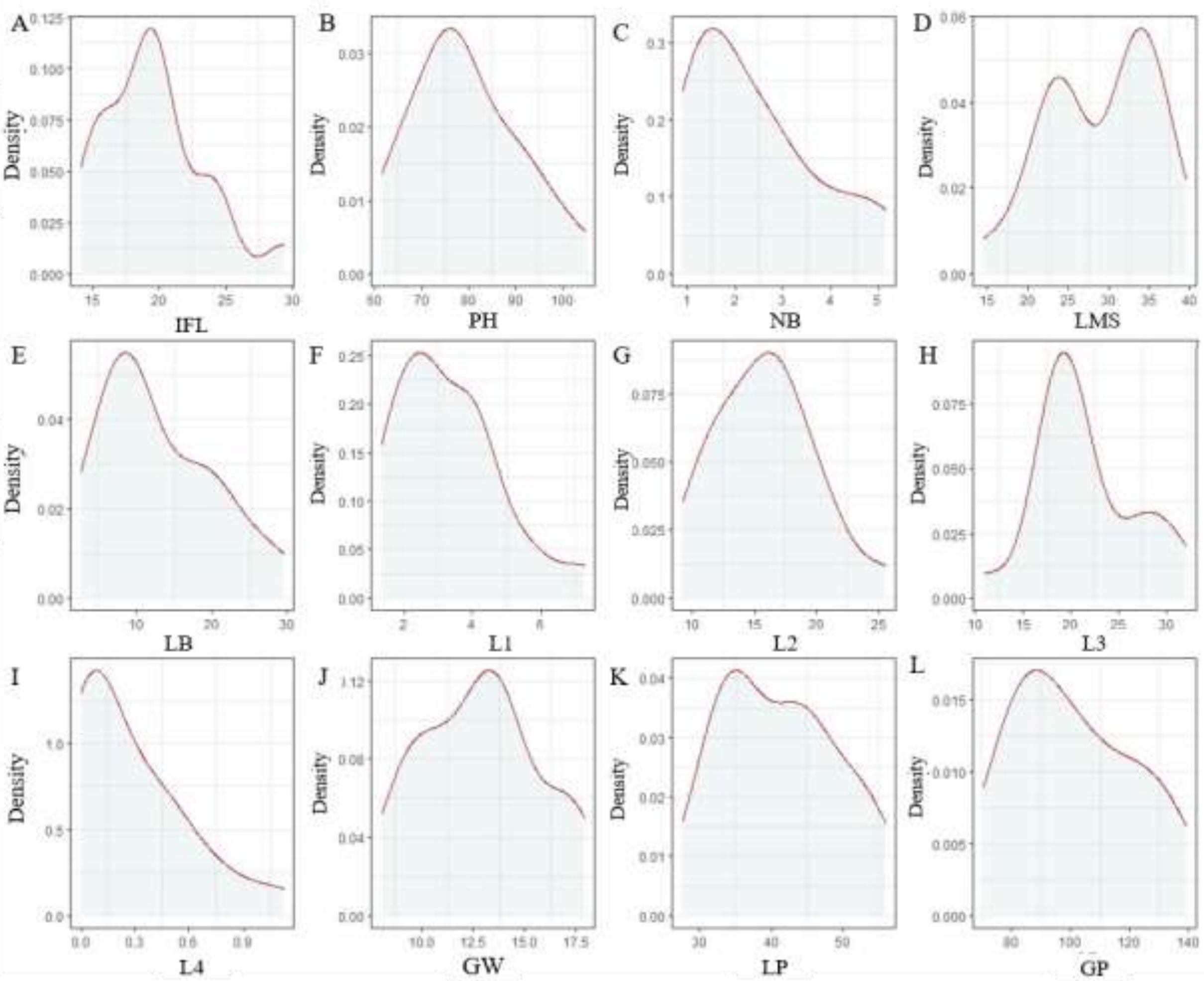

FIGURE 1 - Density parameters on soybean yield components, submitted to nine treatments (soybean genotypes (50i52 RSF IPRO, 55I57RSF IPRO, DM 57i52 IPRO, BMX Lança 58i60 RSF IPRO, M 5838 IPRO) and four previous coverages (linseed, oats, wheat and pasture). On the variables height of insertion of the first legume (IFL), plant height (PH), number of branches per plant (NB), number of legume s on the main stem (LMS), number of legumes in the branches (LB) number of legumes containing only one seed (L1), two seeds (L2) three seeds (L3) four seeds (L4), grain weight per plant (GW), number of legumes per plant (LP) and grains per plant (GP).

Figure 2 shows the productivity and nutritional quality of the grains. Where the thousand grain weight (Figure 2a) exhibited a maximum amplitude of 120 g, being one of the main components of productivity and a genetically determined attribute, but strongly influenced by the environment (RIBEIRO et al., 2016). The final productivity (Figure 2b) expressed from 3 to 3.5 ton ha^{-1}, with a percentage of 40% of green grains (Figure 2c). The greenish color of soybean grains is the result of several factors, which may be genetic in which genotypes whose seed chlorophyll is inserted into the tegument, even when mature or environmental caused by environmental stresses that lead to premature death or forced maturation of the plant (FRANÇA-NETO et al., 2005).

The nutritional composition of soybeans depends both on the genetics of the genotype and on the soil and climate conditions in which the plant was grown. However, most oilseed cultivars exhibit from 30% to 45% of proteins and from 15% to 25% of oil, 5% of mineral material, since the total carbohydrate content in the soybean grain is approximately 34% and 10 % of that percentage. Esterified triglycerides represent 9.3% to 17.3% of total lipids. Among the fatty acids present in triglycerides are stearic acids 2.2% to 7%, oleic acids 15.2% to 25.6%, linoleic acids 33.8% to 59.6% and linolenic acids 4.3% to 15 % (BORDIGNON;

MANDARINO, 1994). Regarding these data, those found in Figure 2 are within this pattern, the total protein content (2d) was 31.5%, the oil content (2e) 19 to 20%, the crude fiber content (2f) 5.25 to 5.5%, mineral matter content (g) 5.15 to 5.20%, palmitic acids (2h) 12%, stearic (2i) 4.6%, oleic (2j) 23 %, linoleic (2k) 54% and linolenic (2l) 6%.

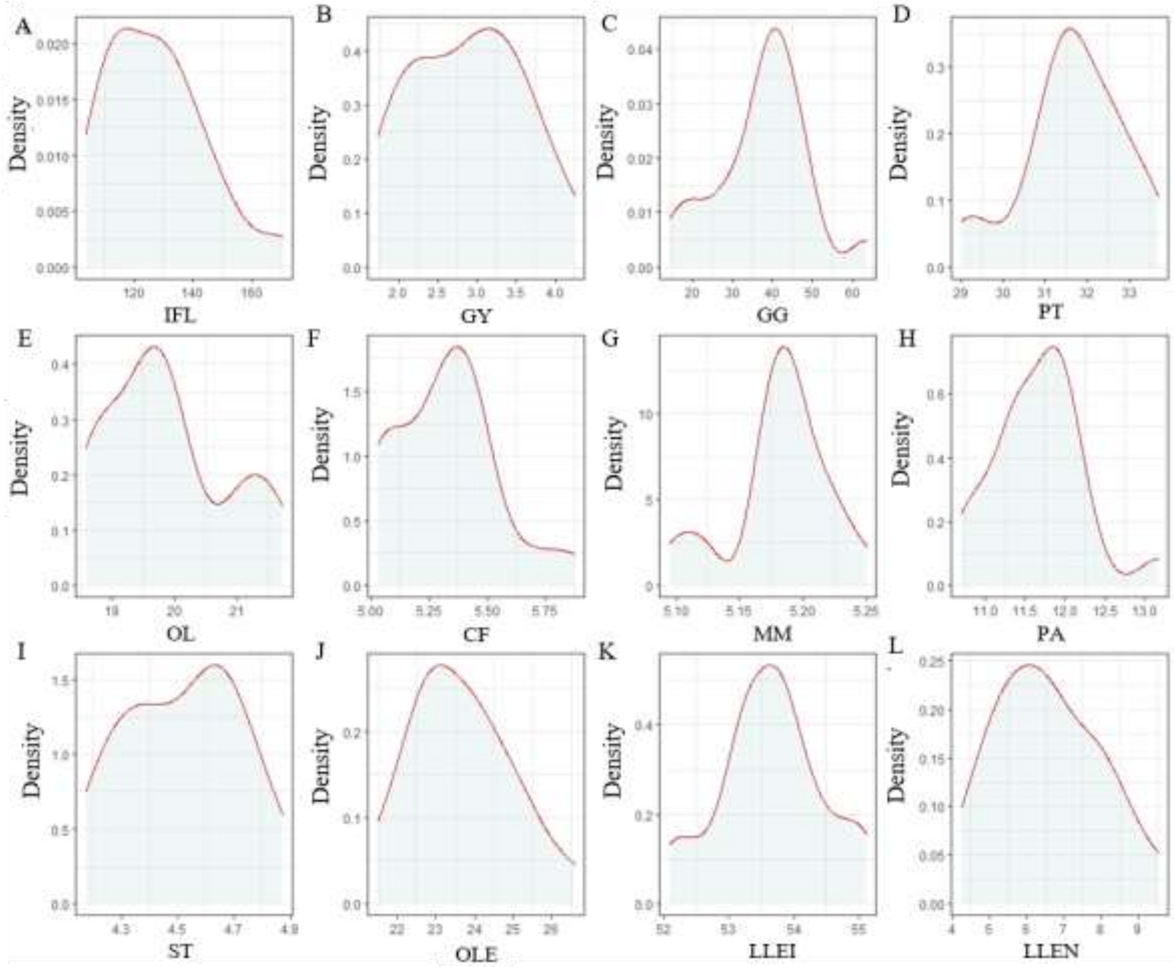

FIGURE 2 - Parameters of density in productivity and nutritional quality of soybeans, submitted to nine treatments soybean genotypes (50i52 RSF IPRO, 55I57RSF IPRO, DM 57i52 IPRO, BMX Lança 58i60 RSF IPRO, M 5838 IPRO) and four previous coverages (linseed, oat, wheat and pasture)}. About the variables: thousand grain weight (TGW), grain yield (GY), percentage of green grains (GG), total grain protein (PT), grain oil (OL), crude grain fiber (CF), grain mineral material (MM), grain palmitic fatty acid (PA), grain stearic acid (ST), grain oleic fatty acid (OLE), grain linoleic acid (LLEI), grain linolenic acid (LLEN).

Regarding the bromatological quality of soybean plants (Figure 3) the crude protein (3 a) was around 16%, while acid and neutral detergent fibers (Figure 3b, Figure 3c) exposed 27% and 41% respectively. The lipid content (Figure 3d) was concentrated in 1.9%, the mineral material (Figure 3e) in 4%, carbohydrate (Figure 3f) and lignin (Figure 3g) presented approximate values of 7% and 10%, respectively. Similar results were found in the work carried out by Dias et al. (2010), which evaluated the mineral material (5.7%), crude protein (15.13%), neutral detergent fiber (50%), acid detergent fiber (42.17%), lignin (10.7%), oil (2.23%) and total carbohydrates (8.3%). Regarding the chemical composition of the leaf tissue of the plants, the calcium content (Figure 3h) was 1.4%, phosphorus (Figure 3i) around 0.19%, potassium (Figure 3j), approximately 1.1% , magnesium (Figure 3k) 0.35% and sulfur (Figure 3l) 0.2%. According to the Fertilization and Liming Manual for the States of Rio Grande do Sul and Santa Catarina (2004), they are within the ranges of macronutrients and micronutrients considered suitable for the development of soybean crops.

The interaction between agronomic variables is important because it allows verifying the degree of interference of one trait on another, whether positive or negative. Thus, Pearson's linear correlation coefficient is used to demonstrate the level of connectivity between two or more variables. When the correlation coefficient estimates are positive, they indicate a tendency for one variable to increase when the other increases and, negative correlations indicate a tendency for one variable to increase while the other decreases (ZUFFO et al., 2018).

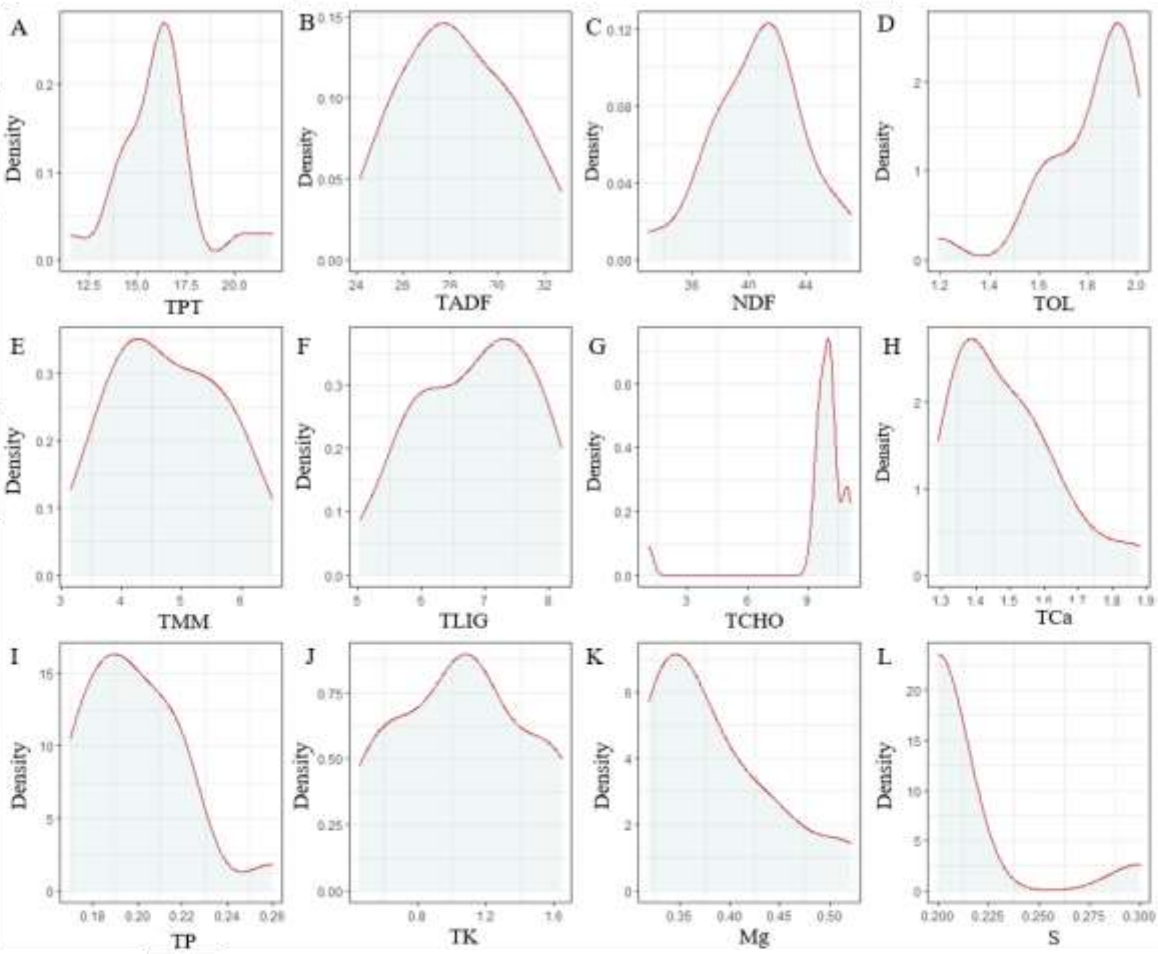

FIGURE 3 - Density parameters in bromatological and chemical quality of soybean plants, submitted to nine treatments (soybean genotypes (50i52 RSF IPRO, 55I57RSF IPRO, DM 57i52 IPRO, BMX Lança 58i60 RSF IPRO, M 5838 IPRO) and four previous coverages (linseed, oat, wheat and pasture). About the variables crude plant protein (TPT), acid detergent fiber (TADF) and neutral detergent fiber (NDF), plant oil (TOL), plant mineral material (TMM), plant lignin (TLIG), plant carbohydrates (TCHO), plant calcium (TCa), plant phosphorus (TP), plant potassium (TK), plant magnesium (Mg) and plant sulfur (S).

The values obtained for the correlation indicate that there was a positive and significant association between grain yield (GY) with crude fiber (CF) and linolenic fatty acid (LLEN) of the grain. The higher the grain yield, the lower the percentage of stearic fatty acid (ST) and oleic fatty acid (OLE), given the negative interaction between these variables. A similar pattern was for the percentage of green grains (GG) in which there was a negative interaction with oleic fatty acid and a positive interaction with linolenic fatty acid.

Observe a negative and significant association between grain protein (PT) and oil (OL) and linolenic fatty acid present in the grain, that is, the higher the protein content, the lower the percentage of OL and LLEN present in the grain. The same effect was for plant phosphorus (TP) and protein (TPT). There was also a positive interaction with grain stearic fatty acid (ST) and plant lignin content (TLIG). The oil content showed a positive interaction with grain linolenic fatty acid and phosphorus (TP), plant potassium (TK) and a negative interaction with grain stearic fatty acid and linoleic acid. The mineral material (MM) of the grain showed a negative interaction with calcium (TCa) and magnesium (TMg), so the higher the MM content of the grain, the lower the total TCa and TMg content of the plant will be. However, it showed a positive and significant interaction with neutral detergent fiber (TNDF) and plant TK.

Plant phosphorus content (TP) showed a significant and positive interaction with protein (TPT), TK, plant sulfur (TS) and LLEN content. However, it had a negative relationship with ST, LLEI and TLIG. That is, the higher the phosphorus content in the plant, the lower the amount of ST and LLEI in the grain and a lower content of lignin in the plant. In relation to potassium in the plant, the higher the content, the lower the content of lignin, calcium and magnesium in the plant and ST and LLEI in the grains. However, the higher the LLEN content in the grain will be. Plant magnesium (TMg) showed a significant and positive correlation with TCa, which showed a negative interaction with TNDF. When we take into account the total protein content of the plant, we can observe that there was a positive interaction with the content of sulfur, magnesium, phosphorus, calcium. Moreover, a negative interaction with grain LLEI and plant TNDF and TLIG.

Regarding the environmental variables measured in combination, the resulting ordering graph showed a distinct partition of the analyzed variables in relation to the treatments (Figure 5). The ranking chart shows that the first two components explain 51.4% of the total variation in environmental data, of the total variance (PC1 = 28.8% and PC2 = 22.6%). The eigenvalues represent the total variation explained for each factor, with only the first component explaining 28.8% of the data variability.

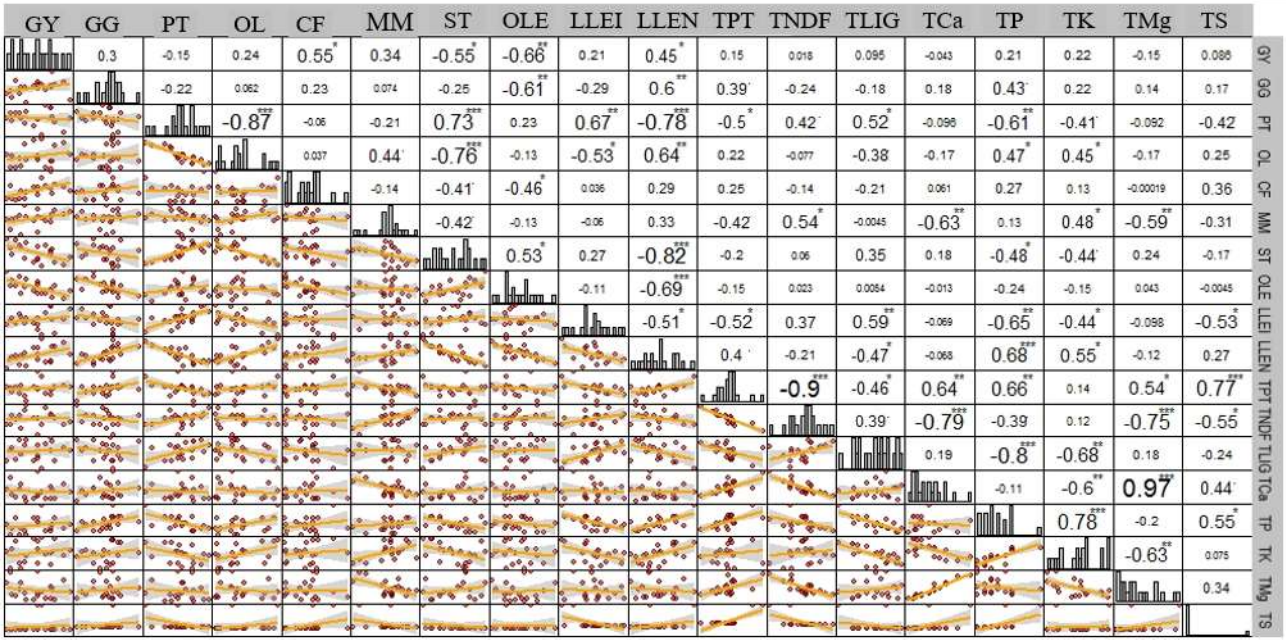

FIGURE 4 - Pearson's correlation coefficients in soybeans between the characters: grain yield (GY), green grains (GG), grain protein (PT), grain oil (OL), crude grain fiber (CF), mineral material (MM), stearic acid (ST), oleic acid of grain (OLE), linoleic acid of grain (LLEI), linolenic acid of grain (LLEN), crude plant protein (TPT), plant neutral detergent fiber (TNDF), plant lignin (TLIG), plant calcium (TCa), plant phosphorus (TP), plant potassium (TK), plant magnesium (TMg) and plant sulfur (TS). *Significant at 5% by the t test; **Significant at 1% by the t test; ***Significant at 0.1% by t test.

According to the modeling done, it can be said that the samples belonging to the first group, in Quadrant 1, were chemical qualities (TPT, TMM, TOL, TCHO) and chemical qualities of soybean plants (TCa, TP, TK, TMg, TS) and productivity (PH, TGW), showing a specific relationship with the treatment M 5838 IPRO/ Wheat, BMX Raio IPRO/ Wheat, BMX Zeus IPRO/ Linseed and BMX Zeus IPRO/ Wheat. Thus, it is clear that the treatments located in this quadrant have a higher nutritional and chemical quality of soybean plants.

While for the second group, in Quadrant 2, the significant variables were nutritional quality of grains (PT, CF, OL, MM, LLEN) and productivity (GG, LP, L2, L3, L4, GW, GY, GP). These variables were related to the treatments BMX Raio IPRO/ Linseed, BMX Raio IPRO/ Oats, BMX Zeus IPRO/ Oats, DM57i52 IPRO/ Wheat, DM57i52 IPRO/ Linseed. In Quadrant 2, the main components of grain productivity and nutrition were concentrated, which indicates that these treatments, in addition to presenting higher yields, also presented a better nutritional quality of the grains.

The variables from the Quadrant 3, on the other hand, were relevant: TLIG, PA, LMS, LLEI, TADF, TNDF, NB, LB, which interacted with the soybean cultivar BMX Lança IPRO on the four coverages (wheat, pasture, linseed and oat (Iapar -19 Pioneira). Which leads to the realization that the cultivar is linked to a higher fiber content, both in the grain and in the plant. In Quadrant 4, the variables that showed significance were ST, LLEI, IFL, which interacted with the treatments M 5838 IPRO/ Pasture, M 5838 IPRO/ Linseed, M5838 IPRO/ Oat, BMX Raio IPRO/ Pasture, DM57i52 IPRO/ Pasture, DM57i52 IPRO/ Oat.

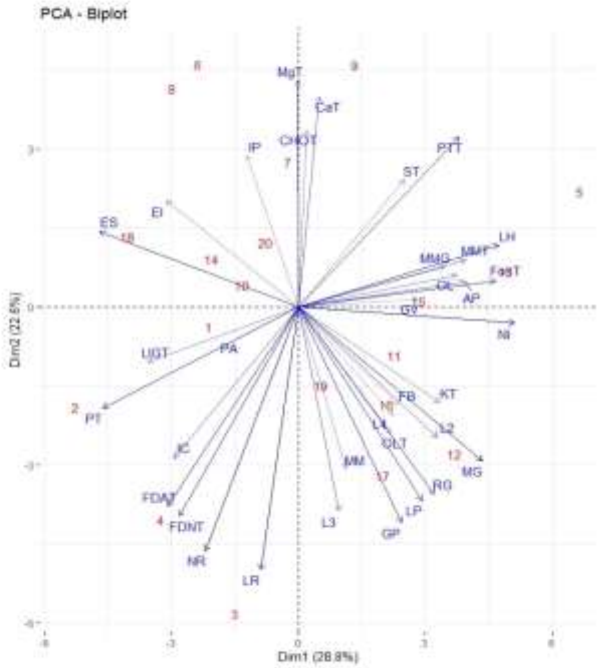

FIGURE 5 - Biplot analysis based on principal component analysis (PCA) for yield traits and nutritional quality of soybean plants and grains produced on different soil covers. The two main components (PC1 and PC2) explained 51.4% of the total variation in the data. Numbers represent all treatments combined 1 (BMX Lança IPRO/ Wheat), 2 (BMX Lança IPRO/ Pasture), 3 (BMX Lança IPRO/ Linseed), 4 (BMX Lança IPRO/ Oats), 5 (M5838 IPRO/ Wheat), 6 (M5838 IPRO/ Pasture), 7 (M5838 IPRO/ Linseed), 8 (M5838 IPRO/ Oats), 9 (BMX Raio IPRO/ Wheat), 10 (BMX Raio IPRO/ Pasture), 11 (BMX Raio IPRO/ Linseed), 12 (BMX Raio IPRO / Oats), 13 (BMX Zeus IPRO / Wheat), 14 (BMX Zeus IPRO / Pasture), 15 (BMX Zeus IPRO / Linseed), 16 (BMX Zeus IPRO / Oats), 17 (DM57i52 IPRO/ Wheat), 18 (DM57i52 IPRO/ Pasture), 19 (DM57i52 IPRO/ Linseed), 20 (DM57i52 IPRO/Oat). And the studied variables of the nutritional and mineral character of the plant (total protein (TPT), acid detergent fiber (TADF) and neutral detergent fiber (TNDF), oil (TOL) mineral material (TMM), lignin (TLIG), carbohydrates (TCHO), calcium (TCa), phosphorus (TP), potassium (TK), magnesium (TMg), sulfur (TS). Productivity and nutritional quality of grains (height of insertion of the first legume (IFL), height of the plant (PH), number of branches per plant (NB), number of legumes on the main stem (LMS), number of legumes on branches (LB) number of legumes containing only one seed (L1), two seeds (L2) three seeds (L3)) four seeds (L4), grain weight per plant (GW), number of legumes per plant (LP), grains per plant (GP), thousand grain weight (TGW), grain yield (GY), percentage of grains (GV), total grain protein (PT), grain oil (OL), crude grain fiber (CF), grain mineral material (MM), grain palmitic fatty acid (PA), stearic fatty acid grain (ST), grain oleic fatty acid (OLE), grain linoleic acid (LLEI), grain linolenic acid (LLEN).

Cluster analysis (dendrogram) gathers sample data into groups, taking into account some criteria, including homogeneity within the group and heterogeneity between groups. The genetic distance analysis generated the "cluster", which shows the separation of accessions into four main groups (Figure 6). The first group, which was divided into two, includes the 5 soybean cultivars (BMX Lança IPRO, M5838 IPRO, BMX Raio IPRO, BMX Zeus IPRO, DM57i52 IPRO) cultivated on pasture, and three (DM 57i52 IPRO, BMX Raio IPRO, M5838 IPRO) on oats. This indicates that regardless of the soybean cultivar, the effect that the pasture promotes on the productive characteristics, nutritional quality of the grains, chemical and chemical aspects of the plant is the same.

The second group includes 1 cover, which is wheat and two soybean cultivars (DM 57i52 IPRO, BMX Zeus IPRO), which have a similar development cycle. The third group has two predecessor cultures: wheat and linseed and the cultivars BMX Lança IPRO, M 5838 IPRO, DM57i52 IPRO IPRO. The fourth group had all the predecessor crops (oat, wheat, linseed) except for the pasture, and four of the soybean varieties (BMX Lança IPRO, M 5838 IPRO, BMX Raio IPRO, BMX Zeus IPRO), however they had subgroups according to the predecessor crop.

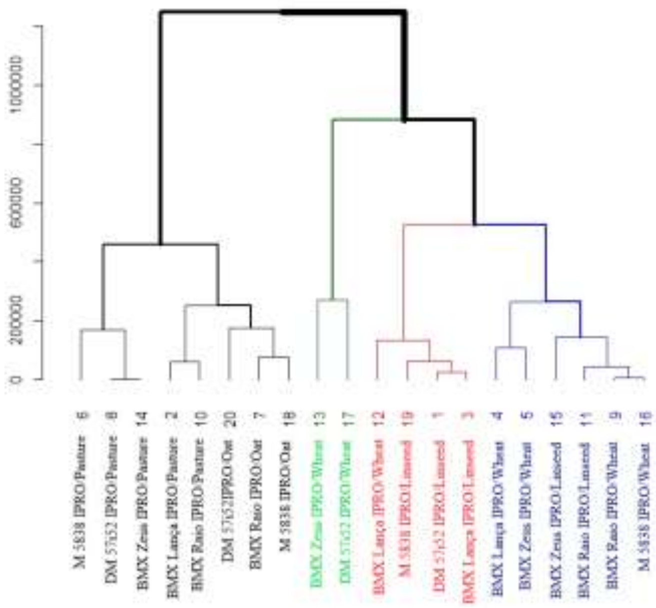

FIGURE 6 - Dendrogram of divergence between treatments, based on twenty-seven morphological characters, estimated by Euclidean distance.

The use of cover crops is one of the main alternatives for winter crops, in order to minimize the effects of pests, diseases and nutritional deficiencies, thus reducing dependence on synthetic molecules, as well as reducing production costs. In addition to these benefits, cover crops improve the chemical, physical and biological quality of the soil, proving to be a promising alternative for farmers, who aim to improve soil quality.

CONCLUSIONS

It is not possible to perceive a significant effect between the variables analyzed and the predecessor cultures used, in addition to the fact that in relation to bromatological quality, plant chemistry, productivity and nutritional quality of the grains, they presented values consistent with the literature.

The predecessor crops (oat, pasture, wheat and flaxseed) did not directly interfere in the physicochemical composition of the soybean crop.

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