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Performance of the soybean crop produced with on-farm and chemicals bioinputs to control pests and diseases

Desempenho da cultura da soja produzida com produtos químicos e bioinsumos on-farm para controle de pragas e doenças

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ABSTRACT

The soybean crop is one of the most representative oilseeds in the world, and its high grain yield also means that chemical products are very widely used to control pests and diseases. In this sense, alternative forms of control such as the use of beneficial microorganisms multiplied by the farmer himself are advantageous. The study aimed to evaluate the performance of the soybean crop cultivated with the use of on-farm chemical and biological products (Bioinputs) to control pests and diseases. The experiment was conducted under field conditions in a commercial crop area under natural climate conditions with three replications for each treatment, being agrochemicals and other bioinputs. The multiplication of bioinputs took place on the field property. The plant dry matter was evaluated at the phenological stage of R2, the number of pods and the number of grains per pod and grain weight, occurred at physiological maturation. The protein grain content in soybean grains were determined. Dry matter (2515 kg ha^{-1}), grain weight (149.3g) and grain protein (43%) showed no statistical difference between managements with agrochemicals and bioinputs. The number of pods, grains per pod and grain yield (1523 versus 2380 kg ha^{-1}) was higher in the chemical production system, which may be associated with the water deficit that occurred during the experiment, disfavoring the microorganisms of the bioinputs. Therefore, compared with crop bioinputs, chemical management presented higher soybean grain yield (36%) in a year of water deficit.

KEYWORDS: *Glycine max;* beneficial microorganisms; biological inputs; biological control.

RESUMO

A cultura da soja é umas das oleaginosas de maior representação mundial e sua alta produção representa também um alto consumo de produtos químicos para controle de pragas e doenças. Nesse sentido, formas alternativas de controle como uso de microrganismos benéficos multiplicados pelo próprio agricultor são vantajosas. O objetivo do estudo foi avaliar o desempenho da cultura da soja cultivada com o uso de produtos químicos e biológicos *on-farm* (Bioinsumos) para o controle de pragas e doenças. O experimento foi conduzido em condições de campo em área de lavoura comercial sob condições naturais de clima com três repetições para cada tratamento, sendo agroquímicos e outro bioinsumos. A multiplicação dos bioinsumos deu-se na propriedade rural. A avaliação de matéria seca de plantas foi no estádio fenológico de R2, o número de vagens e o número de grãos por vagens e peso de grãos, ocorreram na maturação fisiológica, sendo determinado o teor de proteína nos grãos de soja. A matéria seca (2515 kg ha^{-1}), peso de grãos (149,3g) e proteína em grãos (43%) não apresentaram diferença estatística, entre os manejos com agroquímicos e bioinsumos. O número de vagens, grãos por vagem e a produção de grãos (1523 versus 2380 kg ha^{-1}) foi maior no sistema químico de produção, podendo ser associado ao déficit hídrico que ocorreu durante o experimento, desfavorecendo os microrganismos dos bioinsumos. Portanto, o manejo químico, comparado com bioinsumos da lavoura apresenta maior produção de grãos de soja (36%) em ano de déficit hídrico.

PALAVRAS-CHAVE: *Glycine max;* microrganismos benéficos; insumos biológicos; controle biológico.

INTRODUCTION

The soybean crop (*Glycine max* (L.) Merrill) has its origin in Asia and its implementation in Brazilian agriculture represents a milestone in the country's agricultural sector. In terms of production, according to the national supply company, the area cultivated with soybean in Brazil in the 2021/22 harvest was 41.5 million hectares, with a production of 125.6 million tons of grains and the projection for the 2022/23 harvest was should be around 155.7 million tons of grains, cultivated in 44.1 million hectares (CONAB 2022). This crop is still one of the most important oilseeds in the world, with oil percentages of approximately 20% and protein of 40%, being widely used with human and animal food, among other products (TAGLIAPIETRA et al. 2022).

The large volume of soybean produced in the world and in Brazil is the result of the use of technologies created during the green revolution, such as machines, implements, transgenics, fertilizers and agrochemicals. According to OGINO & BACHA (2021), the consumption of agrochemicals in Brazil between the years 1990 and 2010 increased from around 50 thousand tons to 300 thousand tons, a sixfold increase in consumption in 20 years. While in the last 10 years, the national market has seen a 190% increase in the use of agrochemicals (TAVARES et al. 2020). Among Brazilian crops, soy when added to sugarcane and corn, correspond to 70% of all agrochemicals used in Brazil, an approximate average of 23.3% for each crop (BOTELHO et al. 2020).

To reduce the use of agrochemicals in soybean production areas, biological inputs or bioinputs appear. Among the bioinputs, communities of microorganisms stand out, which according to VIDAL et al. (2020), are a set microbial cells that have multifunctional properties, and can act as biological agents to control pests and diseases, biostimulants and biofertilizers. In 2020, around 94 biofuels were registered, 19% higher than in 2019 in Brazil (SAUSEN et al. 2021). In the year 2023, 90 new bioinputs were registered in Brazil (MAPA 2024). Still according to SAUSEN et al. (2021), the use of these products, in addition to being a tool for agricultural production, is also considered a management that helps to reduce cases of resistance to pests and diseases.

The first part of a spectrum of possibilities and management to be conducted with bioinputs is the combination of more than one genus of bacteria, known as coinoculation, which has, among other functions, for example, carrying out biological nitrogen fixation (BNF). Study of KORBER et al. (2021), showed that the coinoculation of *Bacillus japonicium* + *Azospirillum brasilense* has higher percentage of germination and root length in soybean plants. In this way, a more developed root system can bring advantages to the plant in situations of water deficit, as it will be able to capture water in deeper layers of the soil.

Bioinputs are also efficient in controlling fungal diseases such as *Rhizoctonia solani*, the main soil fungus that has attacked soybean in recent years, a fungus that, when subjected to treatments using *Bacillus subtilis* and *Bacillus pumilus*, had its incidence and decreased severity, and consequently, led to better establishment of soybean plants (COELHO et al. 2021). Still, the healthy permanence of structures such as leaves, which are not affected by damage from pests and diseases, has a direct and positive connection, with factors such as weight of a thousand grains, number of pods and the protein content of soybean grains (ZUFFO et al. 2022). The association of fungicides based on *Bacillus subtilis*, with fungicide programs to be applied to soybean, it was possible to observe better powdery mildew control and, consequently, higher productivity, when applied in the reproductive phase of soybean (SCHOTT et al. 2021). That is, the use of biological products to control diseases that interfere with the health of leaves and, in turn, reduce the area of photosynthesis and subsequent grain yield, are essential tools for crops and phytosanitary management.

In addition to the advantages of bioinputs, what has helped to expand their “on-farm” system. This term has been gaining ground in recent decades, as it allows each producer, from the acquisition or construction of biofactories, strains of beneficial microorganisms and the culture medium, to produce their own bioinput at low cost. The premise of using on-farm multiplication is to allow the producer to develop his own biological input with action to stimulate plant growth and nutrition or those with a biopesticide or biofungicide function, aiming to decrease production costs (SANTOS et al. 2020).

The production of on-farm bioinputs requires qualified labor, in addition to an understanding of ecological-based agriculture, as it is different from conventional agriculture. Another very important aspect is water quality, free from contaminants, with adjusted pH, free chlorine or other compounds that could inactivate microorganisms of interest or multiply organisms that are not welcome in soil and agriculture (SANTOS et al. 2020, HARDOIM et al. 2022). However, according to SANTOS et al. (2020), if a sequence of production practices is followed and with quality, and combined with good technical support, it is possible to develop on-farm production safely and efficiently. Finally, it could be an opportunity to access market niches, through the carbon market, ecosystem services and in the future some seal of appreciation for sustainable production.

Thus, in this context, the study objective was evaluate the performance of the soybean crop grown using chemical and biological products on the farm to control pests and diseases.

MATERIAL AND METHODS

The study was conducted in a crop area under a consolidated no-tillage system with annual crops in succession, soybean in the summer and oats in the winter, in Campo Santo, district of the of Coronel Bicaco, RS. The region's climate is characterized as type Cfa according to the Köppen classification (KUINCHTNER & BURIOL 2001) and predominant soil type Oxissol (SANTOS et al. 2018).

The crop area used for the experiment was a 10-year consolidated no-till system, cultivated with grain crop rotation, spring/summer (corn or soybean) and autumn/winter (wheat or ryegrass pasture). A seven-hectare crop area was used for soybean cultivation in the system with on-farm biological inputs and an adjacent with chemical model, with the two areas divided in a north-south direction and subdivided into three plots each. The experiment was conducted under field conditions without irrigation. Climate monitoring was conducted via the National Institute of Meteorology - INMET's automatic meteorological station in Santo Augusto, RS (Figure 1).

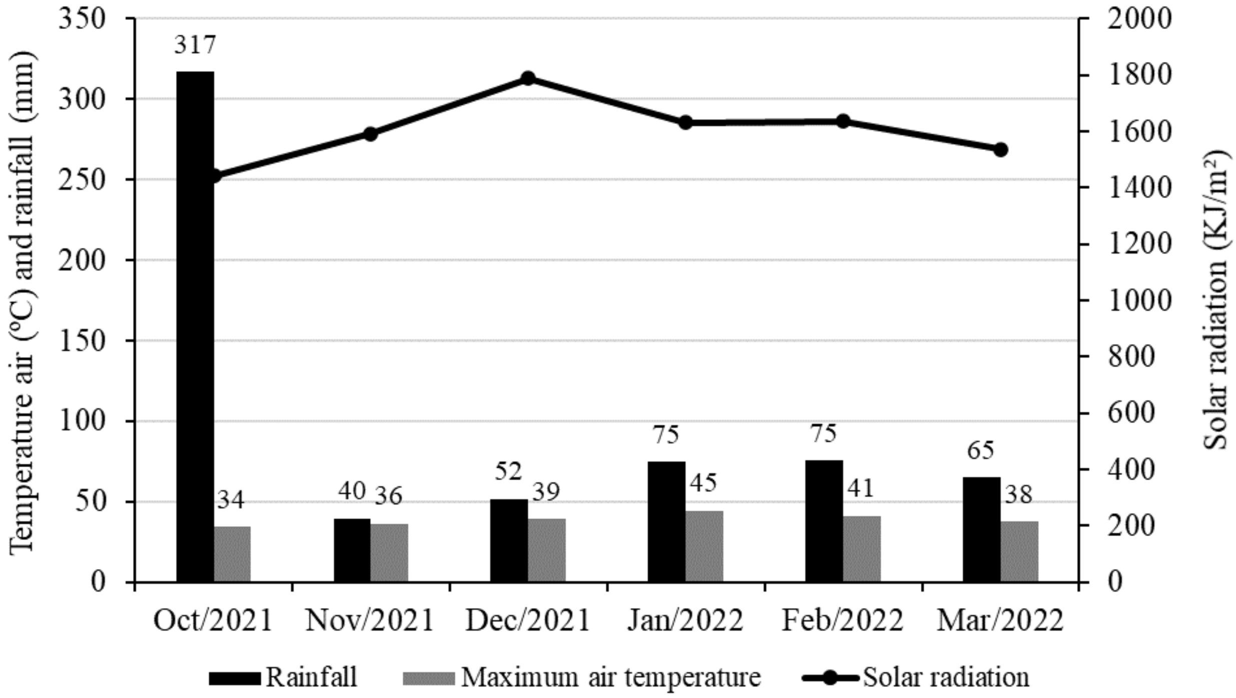

Figure 1. Climatic data of air temperature, rainfall and solar radiation recorded by the meteorological station of Santo Augusto, RS (ID Station A805). Source: INMET (2022).

Soybean sowing took place within the agroclimatic climate risk zoning (ZARC) in October 2021 using a seeder coupled to a tractor. Fertilization was used in accordance with SBCS (2016). The soil contained organic matter (3.3%), pH (5.64), aluminum (0%), P (21.1 mg/dm³), K (288 mg/dm³), Ca (12.1 mg/dm³) and Mg (8.2 mg/dm³). The variety used was FPS RR1859, maturation group 5.9, early cycle, indeterminate growth habit, average plant height and medium/high requirement for soil fertility. Seed treatment for both cultivation conditions, agrochemicals and bioinputs, was with Standak Top UBS® at a dose of 200 ml/100 kg of seeds. Still, on the sowing day, seeds were inoculated with *Bradyrhizobium japonicum* to distribute 100ml/100 kg of seeds. The final distribution of soybean seeds in the field was 16 plants per linear meter and 50 cm between rows, with a projection of 320,000 plants/ha.

The biological inputs were made on the rural property, the biofactory consisted of a 250-liter (type water tank), pump for stirring the syrup and activating the multiplication. The acquisition of strains of microorganisms was from companies specialized in the genre, with a guarantee of at least 2 x 10^{11} Colony

Forming Units (CFU). The multiplication of microorganisms process began with cleaning the tank with disinfectant products, then adding the strains and culture medium in distilled water, with adequate pH, without chlorine or other compounds that could inactivate the microorganisms of interest or multiply undesirable organisms, in doses pre-established by the manufacturers. The multiplication time for strains on the market was 24 to 48 hours, depending on the microorganism. During multiplication, circular stirring was conducted and air was added through the “Venturi” tube.

Applications for both treatments for pest and disease control, both chemical and biological, occurred on three dates, 11/27/2021, 01/06/2022 and 01/27/22. For biological treatment, *Chromobacterium subtsugae* - 4 liters/ha, *Baccilus pumilus*, *Baccilus subitullis, Baccilus amyloliquefaciens* - 2 liters/ha and *Bacillus thuringigiengis* vr. aizawai (BTA), *Bacillus thuringigiengis* vr. kustaki (BTK) - 2 liters/ha, these bioinputs were chosen considering the availability in the region.

In the production system with chemicals, the phytosanitary treatments used were Aproach Prima® (300 ml/ha), Viovan® (600 ml/ha), Vessaria® (600 ml/ha), Expedition® (300 ml/ha), Interpredi Edge® (250 ml/ha) and Intrepid 240® (500 ml/ha), for disease and insect control respectively. Monitoring always aimed to assess the intensity of attack by pests and diseases and the field conditions for application through visits to areas and index images of the Vegetation with Normalized Difference (NDVI), collected by a specialized program for such FieldView® function. Biological products were applied alone, without mixing chemicals in the aerosol tank with a tractor acopled sprayer.

The dry matter evaluation of the soybean plants in the two production systems took place at the R2 stage, the moment at flowering of the plants. For this, nine samples of one linear meter each were collected, three in each third of the area. Plant samples were dried for three days at 65 °C.

Also during crop flowering, images of vegetation index with normalized difference were collected. To determine the number of pods per plant, ten plants at physiological maturation stage (R8) were randomly collected in each third of both cultivation conditions, agrochemical and biological. Grain yield evaluation was determined in three collections for each third, with an area of one square meter each, harvested manually on March 22, 2023, in each cultivation condition. Grain yield was expressed in 13% moisture, recommended for soybean. In the weight of a thousand grains, eight samples of 100 grains each were separated, following the methodology recorded in accordance with the “Regras de Análises de Sementes - RAS” (MAPA 2009). For the analysis of the protein grain content, the Kjeldahl method was used (TEDESCO et al. 1995).

The data were submitted to analysis of averages compared by t-test and Pearson correlations analysis, both $p<0.05$ using the statistical analysis program Sisvar (FERREIRA 2011).

RESULTS AND DISCUSSION

The dry matter of shoot of the soybean plants did not differ statistically between the chemical and biological treatment (2,515 kg ha^{-1}), in the same way, for grain weight (149.26g) and protein grain content with 43% (Table 1).

Table 1. Shoot dry matter, thousand-grain weight and protein grain in soybean.

Treatments	Dry matter (kg ha^{-1})	Grain weight (g)	Protein grain (%)
Chemical	2.531±210 A*	155,27±32 A	42,2±5.7 A
Biological	2.500±325 A	143,26±45 A	43,8±4.3 A

*Means followed by the same letter in the variables do not differ statistically (t-test $p<0.05$). ± standard diviation.

Compared to the study CHAGAS JUNIOR et al. (2021), evaluated different doses of inoculants based on *Bacillus* sp., the results showed that a dose of 50 ml of inoculant for each 100 kg of seeds, increased the height of plants, and consequently, their dry mass, this result was opposite to that found in our study. It should also be noted that the strong dry period with low rainfall recorded during the crop cycle (Figure 1) may explain the low dry matter in both treatments. According to TAIZ & ZEIGER (2013), water content up approximately 90% of the mass of green soybean, and participates in essential processes in soybean metabolism. However, a greater presence of nodules and roots was observed in the condition with biological treatment (not evaluated and showed). This finding was also observed by other studies with greater root development, dry matter and number of nodules, but with organic fertilization and without water restriction in soybean crops (SILVA et al. 2019, BRACCINI et al. 2016, RAGAGNIN et al. 2013).

The percentages of protein grain content obtained between the two treatments do not differ statistically, but both reached a value close to that indicated for commercialization. According to ASSEFA et al. (2019), even with the high grain yield achieved in soybean areas, the internationally expected protein standard for commercialization, close to 47%, is still not reached. However, according to OLIVEIRA (2019), this value is hardly found in Brazil, in most cases the national average remains close to 37% in rainfed areas and lower in floodplain areas. According to ZUFFO et al. (2021), in environments with high soil fertility, soybean plants inoculated with *Bradyrhizobium* sp. the percentage of protein in grains can reach up to 45%, the bacteria being efficient in supplying the necessary rates of nitrogen in the soybean crop for later conversion into protein in the grain.

However, according to NAOE et al. (2021), co-inoculation with *Bradyrhizobium japonicum* and *Azospirillum brasilense* did not change the protein content in soybean grains, even with percentage variations of 36 to 41%, and these results are associated with water deficit in the reproductive period of the crop. On the other hand, according to CARVALHO et al. (2020), when conditioned to sowing in lowland areas that do not limit the availability or lack of water, associated with good inoculation of *Bradyrhizobium* sp. it is possible to observe an average percentage of 39% of protein grain in soybean, similar to that observed in dry areas.

Regarding the weight of a thousand grains, according to TAGLIAPIETRA et al. (2022), the agronomic value is 207g for rainfed areas, therefore, higher than the data from our study; already in cultivation without water restriction it can reach values close to 210g. Therefore, the literature values are higher than the data from our study, reinforcing the importance of rainfall in the soybean production system. There was a positive and significant correlation between dry mass and thousand-grain weight (R^2 = 0.70), number of pods and thousand-grain weight (R^2 = 0.98) for the biological treatment. In the chemical treatment, the correlation between weight and grain yield was significant (R^2 = 84). The existing correlation between grain yield and thousand-grain weight is similar to that presented by SMIDERLE et al. (2019), where grain yiel had a direct and positive connection with the weight of a thousand grains, representing R^2 = 0.91.

Regarding the number of pods, an average of 25.8 pods per plant was observed in the biological treatment (Figure 2). As for the division by the number of grains per pod, only those with 1 grain in the biological treatment were superior to the chemical treatment. Pods with 2 and 3 grains represent a greater number and statistical difference in the chemical treatment, with an average of 90.7 pods of 3 grains and 126 pods of 1 grain, against 63 and 117 pods of 3 and 2 grains, respectively, in the biological treatment.

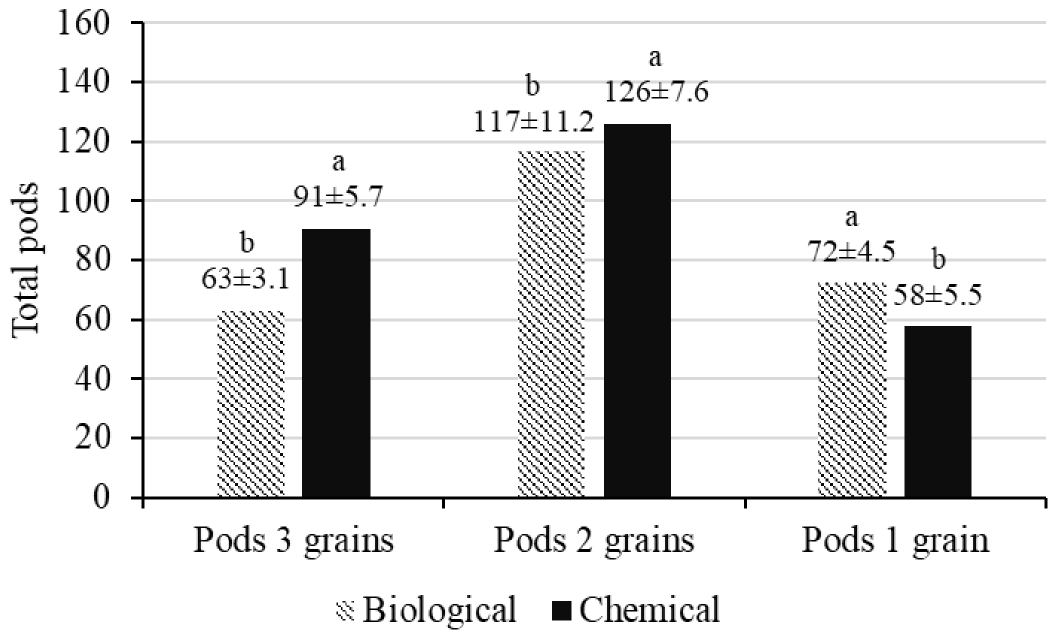

Figure 2. Division by number of grains and total pods per soybean plant. Treatments with the same letter between variables number of grain per pod do not differ statically (t-test p<0.05). ± standard diviation.

In the study by AGUILERA et al. (2020), the joint application of *Azospirillum brasilense* and *Bradyrhizobium japonicum*, and *Trichoderma asperrellum*, in three soybean cultivars, found an average of 53 pods per plant. According to WINCK (2022), the number of pods per plant is influenced by genetic issues and by climatic factors, such as solar radiation, which acts on the setting of flowers, and subsequently pods. According to MARTIN (2022), this is one of the criteria used in wetting programs, as it is intrinsically linked to productivity per area. The pods with two grains were the most representative in both treatments. TAGLIAPIETRA et al. (2022), inferred that the ideal number of grains per pod to reach a productivity of 7 ton ha^{-1} is 2.2 grains/pods, and for the authors this number can be affected by water stress between R2 and R5, in addition to the presence of sucking insects, which corroborates the results of the present study.

Grain yield showed a statistical difference, with biological treatment being the least responsive (1,523 kg ha^{-1}) compared to chemical treatment (2,380 kg ha^{-1}), that is, a difference of 857 kg ha^{-1} or 14.29 bags/60kg/ha^{-1}, corresponding to 36% higher than the biological value (Figure 3).

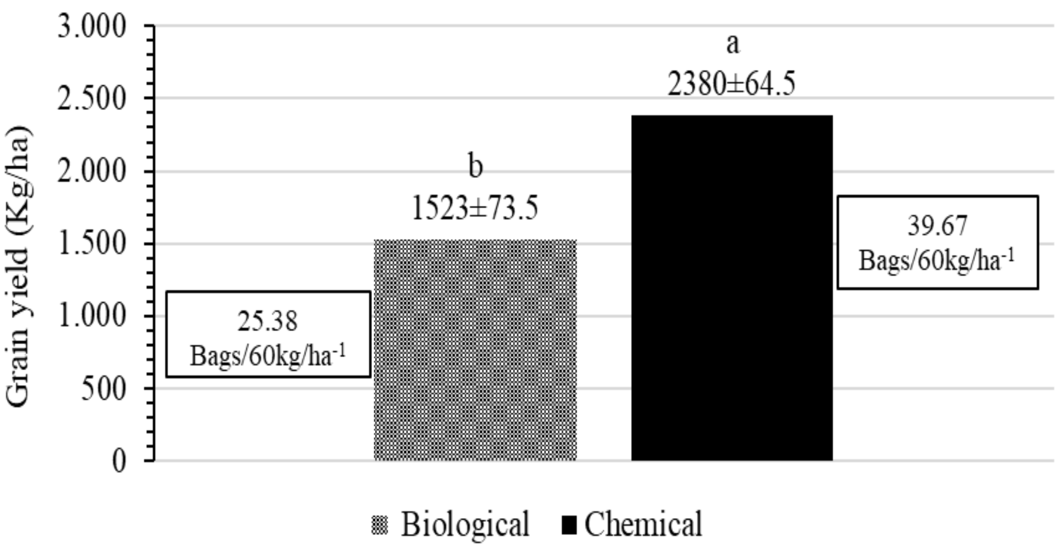

Figure 3. Grain yiel from biologically and chemically grown soybean. Treatments with the same letter do not differ statically (t-test $p<0.05$). ± standard diviation.

This result can be explained through two main lines, linked to plant physiology and the existing relationship between the environment during the crop cycle. Environments with very high temperatures interfere with pollen germination and the structure of the pollen tube, reducing the viability of pollination (SOARES 2016). Not only high temperatures harm the plants, but also according to MARQUES et al. (2011), the absence of water affects essential plant structures such as chlorophyll and carotenoids, which convert light energy into chemical energy, essential for carrying out photosynthesis, and finally converting it into grain yield. When comparing the data from the present study, the chemical treatment stands out with 361 kg per hectare, and the biological one with lower yield, 1241 kg ha^{-1}. According to QUEIROZ REGO et al. (2018), the use of coinoculation with bacteria of the genus *Azospirillum* sp. promote the increase of soybean productivity components, in particular the number of pods per plant, greater number of grains per plant and higher grain productivity, which can reach 719.41 kg ha^{-1} more than without co-inoculation.

In economic terms, taking into account the average price of soybean in April 2022, post-harvest period, R$ 176.6/60kg bag, there would be a revenue of R$ 4,482.00 ha^{-1} for biological treatment and R$ 6,122.00 ha^{-1} for the chemical, totaling R$ 1,640.00 higher than the biological one. When evaluating production costs, according to STABACK et al. (2020), the production of soybean in a system with biological agents for pest control, when compared to a system with chemicals, has a slight increase in grain yield over such a system. In addition, it is possible to decrease the application of inputs such as insecticides by 50%, which represents a greater financial return and sustainability of the system.

However, it should be taken into account that, in the 2021/22 soybean harvest, the state of RS experienced a severe drought, which resulted in significant losses in agricultural areas. According to data from the Instituto Nacional de Metereologia (2022), the raifall for the months of January to March 2022, remained well below the ideal raifall for the time, as well as the air temperature with daily peaks above 40 °C (Figure 1). The presence of these climatic events of extreme intensity, cause disturbances to the plant system. According to TAGLIAPIETRA et al. (2022), for soybean, temperatures above 40 °C in the initial flowering period and consecutive phases can cause abortion of structures such as flowers and vegetables, in the last harvest, periods that remained above 35 °C, caused damage to the leaves. of soybean plants, reducing the productive potential.

Also, according to TAGLIAPIETRA et al. (2022) temperatures above 40 °C promote the degradation of membrane lipids and create a series of reactive oxygens that cause leaf necrosis. These necroses, brown in color and looking like a dry leaf, can be seen in the images of Vegetation with Normalized Difference - NDVI (Figure 4), which showed the differentiation of the color spectrum, the more green, the better the health status of the plants as occurred in the treatment with chemicals, and the closer to the red, the worse the health of the plants, observed in the biological (ZUFFO et al. 2022).

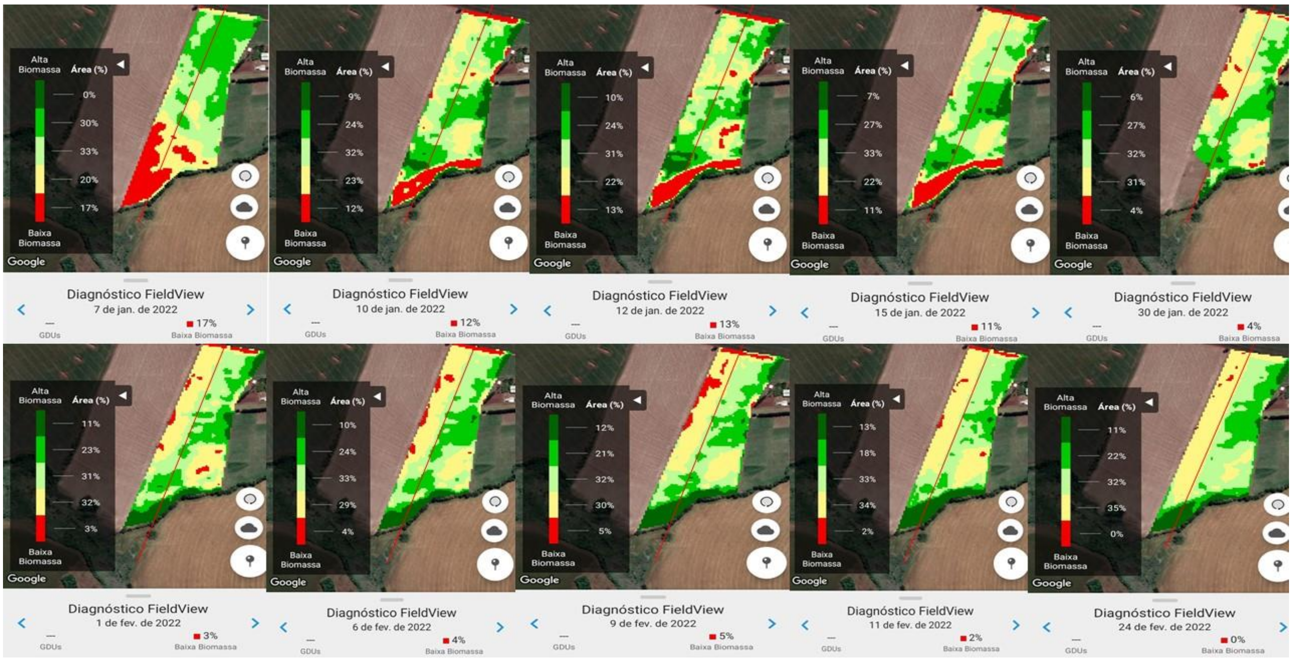

Figure 4. Normalized Difference Vegetation Index - NDVI images, collected from 01/07 to 02/24, 2022, to the left of the vertical line in red of each image, biological treatment and to the right chemical. Source: FieldView® (2022).

The results found for the productivity components of shoot dry mass, number of pods per plant, number of grains per pod and the weight of a thousand grains, in addition to the production in bags per hectare and the protein grain content, were probably affected by abnormal climatic factors, especially the absence of rain (Figure 1). According to GAJIĆ et al. (2018), in the vegetative period that such components are defined, and water deficiency directly affects the final values for the yield components.

BERGAMASCHI et al. (2004), the biggest cause of the reduction in the production of summer crops in RS state of Brazil is the water deficit, due to the quantity and distribution of rainfall (ZANON et al. 2016) with a large evaporative demand in the atmosphere in the season, associated with the irregular distribution of rainfall (ZIPPER et al. 2016). As proof of this question, OLIVEIRA et al. (2021) showed that out irrigation supplementation in soybean in two year harvest (2018/19 and 2019/20) led to a significant increase in productivity of soybean (15%) in the central region of RS, Brazil.

The statistical difference between the results of grain yield and number of pods can be explained, emphasizing, by climatic factors, which negatively affect the beneficial microorganisms of the biological treatment. According to MACHADO et al. (2021), for bacteria of the genus *Bacillus*, for example, the ideal air temperature range for development is 28 to 30 °C, associated with humidity. This being an ideal medium range of air temperature for the applied microorganisms, which, when subjected to high temperatures and lack of water, have their colonies decrease.

CONCLUSION

The performance of the soybean crop in a year of water deficit shows a greater number of pods and grain yield with the use of chemical treatment to control pests and diseases in relation to biological control via on-farm bioinputs.

We suggest new studies in different agricultural years with and without limited rainfall, thus revealing a better reality of the rural farm's field condition.

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