

# COVER CROPS AS A SUSTAINABLE STRATEGY TO INCREASE BLACK BEAN PRODUCTIVITY IN SOUTHERN BRAZIL<sup>1</sup>

## PLANTAS DE COBERTURA COMO ESTRATÉGIA SUSTENTÁVEL PARA AUMENTAR A PRODUTIVIDADE DO FEIJÃO-PRETO NO SUL DO BRASIL

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### ABSTRACT

Cover crops are globally recognized for their potential to improve agricultural soil quality. The use of cover crops, either as single species or in mixtures (mixes), is an effective agronomic practice for sustainable agricultural production, minimizing dependence on external inputs. This study evaluated the effect of winter cover crops on the subsequent cultivation of black bean (*Phaseolus vulgaris* L.) in Southern Brazil over two growing seasons. Different winter cover crops were tested, both individually and in mixtures, including: black oat (*Avena strigosa* Schreb); black oat + common vetch (*Vicia sativa* L.); black oat + common vetch + rye (*Secale cereale* L.) + forage radish (*Raphanus sativus* L.) + white lupin (*Lupinus albus* L.) and control (bare soil). Treatments were arranged in a split-plot experimental design. Yield components and grain yield of black bean grown in succession to the cover crops were determined, with or without supplemental nitrogen fertilization, across two growing seasons (2023/2024 and 2024/2025). Results demonstrated significant increases in black bean productivity in the second season, with 22% in black oat alone, 17% in combination with common vetch, and 22% in mixed species compared to bare soil, even in the absence of nitrogen fertilization. These findings highlight the potential of cover crops to improve soil fertility and reduce dependence on chemical fertilizers. Therefore, cover crops proved to be an effective strategy to enhance black bean productivity, reinforcing the importance of sustainable agricultural practices that improve soil quality and reduce environmental impacts.

**Keywords:** sustainable agriculture; soil cover; crop succession; *Phaseolus vulgaris*.

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## RESUMO

As plantas de cobertura são mundialmente reconhecidas pelo seu potencial de melhorar a qualidade dos solos agrícolas. O uso de plantas de cobertura, isoladas ou consorciadas (mix), se configura como uma prática agrônômica eficiente para a produção agrícola sustentável, minimizando a dependência de insumos externos. Este estudo avaliou o efeito do uso de plantas de cobertura do solo de inverno no cultivo subsequente de feijão-preto (*Phaseolus vulgaris* L.) no Sul do Brasil em dois anos agrícolas. Diferentes plantas de cobertura de inverno foram testadas, de forma isolada e em mix, sendo: aveia-preta (*Avena strigosa* Schreb); aveia-preta + ervilhaca-comum (*Vicia sativa* L.), aveia-preta + ervilhaca-comum + centeio (*Secale cereale* L.) + nabo-forageiro (*Raphanus sativus* L.) + tremoço-branco (*Lupinus albus* L.) e controle (solo descoberto). Os tratamentos foram conduzidos em delineamento experimental com parcelas subdivididas. Foram determinados os componentes de rendimento e o rendimento de grãos da cultura do feijão-preto cultivado em sucessão às plantas de cobertura, associado ou não à adubação nitrogenada em cobertura, em dois anos agrícolas (2023/2024 e 2024/2025). Os resultados demonstraram aumentos significativos na produtividade do feijão-preto na segunda safra, com 22% em aveia-preta isolada, 17% em combinação com ervilhaca-comum e 22% em mix de espécies em comparação com o solo descoberto, mesmo na ausência de fertilização nitrogenada. Essas descobertas destacam o potencial das culturas de cobertura para melhorar a fertilidade do solo e reduzir a dependência de fertilizantes químicos. Portanto, as culturas de cobertura mostraram-se uma estratégia eficaz para aumentar a produtividade do feijão-preto, reforçando a importância de práticas agrícolas sustentáveis que melhoram a qualidade do solo e reduzem os impactos ambientais.

**Palavras-chave:** agricultura sustentável; cobertura do solo; sucessão de culturas; *Phaseolus vulgaris*.

## 1 INTRODUCTION

Currently, several soil conservation practices are being implemented to reduce the environmental impacts of agricultural activities and enhance crop productivity, such as no-tillage, contour farming, and crop rotation (Gomes, 2019). The adoption of soil conservation systems, combined with the use of cover crops, is a promising strategy given its numerous chemical, physical, and biological benefits (Demetrio *et al.*, 2020; Pires *et al.*, 2017; Sá *et al.*, 2009), such as erosion control, nutrient cycling, and the formation and accumulation of soil organic matter (SOM) (Adetunji *et al.*, 2020; Dabney *et al.*, 2010). These benefits can be further enhanced when cover crop mixtures with distinct characteristics are used (Ziech *et al.*, 2015).

Cover crops, whether grown individually or in mixtures, have high biomass production potential and play a key role in nutrient cycling, especially during the decomposition of plant residues (Wolschick *et al.*, 2016). The decomposition rate of these residues is influenced by the plant species involved and is directly related to the carbon/nitrogen (C/N) ratio of the tissues. In general, residues from leguminous species, characterized by a low C/N ratio, decompose faster than those from grasses, which have a high C/N ratio and decompose more slowly (Silva *et al.*, 2021; Carvalho *et al.*, 2013). Thus, the effects of species intercropping are largely dependent on interspecific compatibility, and may contribute to balanced decomposition and nutrient release dynamics in systems exhibiting

functional complementarity. Therefore, combining species with contrasting traits can be a viable strategy to balance the synchronization between nutrient release (particularly N) during decomposition and uptake by subsequent crops, while also providing greater soil cover and physical protection. Additionally, leguminous species have significant potential to N supply through biological nitrogen fixation (BNF) (Rufini *et al.*, 2011). Species such as common vetch (*Vicia sativa* L.) and white lupin (*Lupinus albus* L.) can contribute substantial amounts of fixed N to the soil, ranging from 90-180 and 128-268 kg ha<sup>-1</sup>, respectively (Wutke *et al.*, 2023), potentially benefiting subsequent crops and reducing the need for external N inputs, thereby contributing to both economic and environmental sustainability.

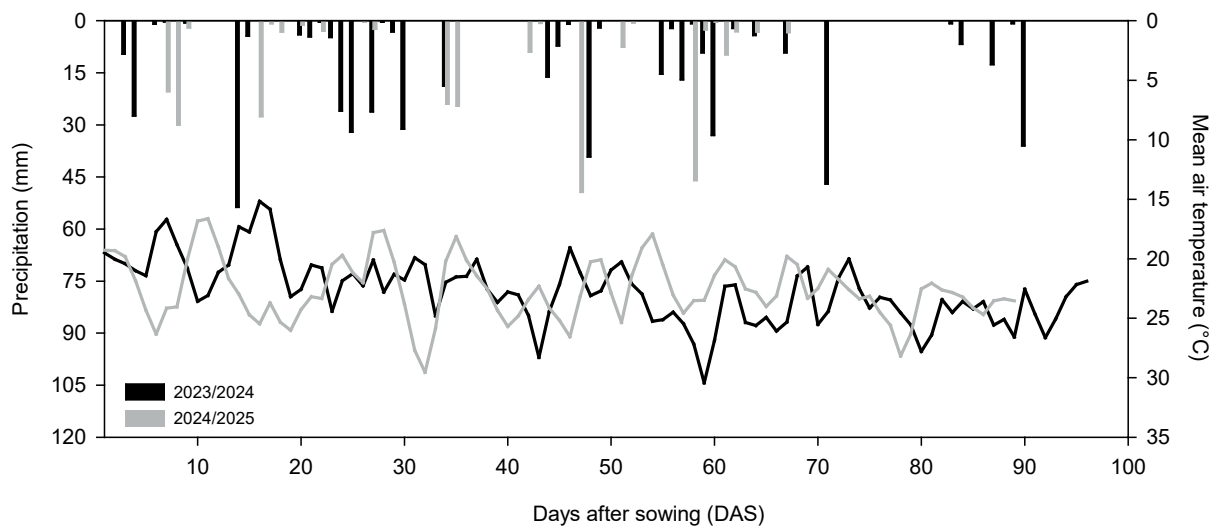
Crops grown in succession to cover crops, such as black bean (*Phaseolus vulgaris* L.), may exhibit significant yield improvements. Black bean, an essential legume in human diets, plays an important role in crop rotation, is capable of BNF, and contributes to soil fertility. Araújo *et al.* (2024) reported that common bean cultivation on legume residues, such as crotalaria ochroleuca (*Crotalaria ochroleuca* G. Don), pigeon pea (*Cajanus cajan* (L.) Hunth), and mucuna (*Mucuna cinereum*), resulted in significant yield increases compared to cultivation in fallow areas. These findings reinforce the importance of careful selection of cover crop species, which can enhance several soil properties. Thus, the strategic use of cover crops preceding commercial crops is an efficient practice that can enhance crop performance, reduce dependence on synthetic chemical inputs, and support the economic and environmental sustainability of agricultural systems. Therefore, the objective of this study was to evaluate the effect of winter cover crops on the subsequent cultivation of black bean in Southern Brazil over two growing seasons.

## 2 MATERIALS AND METHODS

The study was conducted over two consecutive growing seasons, 2023/2024 and 2024/2025, at the State Center for Forest Diagnostics and Research (CEFLOR), belonging to the Department of Agricultural Diagnosis and Research of the Secretariat of Agriculture, Livestock, Sustainable Production, and Irrigation, located in Santa Maria, Rio Grande do Sul, Brazil (29°39'54.9"S and 53°54'39.3"W, 127 m altitude). The soil at the site is classified as an Argissolo Vermelho-amarelo Distrófico típico (Santos *et al.*, 2025), with the following chemical characteristics in the 0-20 cm layer: pH (water, 1:1) 6.1; aluminum 0.1 cmolc dm<sup>-3</sup>; phosphorus 6.8 mg dm<sup>-3</sup>; potassium 104.2 mg dm<sup>-3</sup>; and organic matter 17.5 g kg<sup>-1</sup>. The climate is classified as humid subtropical (type Cfa2 in Köppen's classification), with an average annual temperature of 19.3 °C and annual precipitation of 1,660 mm (Alvares *et al.*, 2013). Climatic data during the experimental period were obtained from an automatic weather station of the National Meteorological Institute (INMET), located at the Federal University of Santa Maria, approximately 19.5 km from the experimental site. During the 2023/2024 growing season, cumulative precipitation was 512.3 mm and average air temperature ranged from 15.2 to 30.4 °C (Figure 1).

In the 2024/2025 season, cumulative precipitation was 276.5 mm and average air temperature ranged from 16.6 to 29.5 °C.

Figure 1 - Daily accumulated precipitation (mm) and average air temperature (°C) during the study period.



Source: Author's construction.

Prior to the experiment, the soil was prepared using a bed shaper and hoe in 2023. The area had previously been cultivated with crotalaria (*Crotalaria spectabilis* Roth.). Winter cover crops were sown on May 30, 2023, and June 4, 2024, using a split-plot experimental design. Treatments included different winter cover crops, both single and mixed species: BO: black oat (*Avena strigosa* Schreb); BO+CV: black oat + common vetch (*Vicia sativa* L.); Mix: black oat + common vetch + rye (*Secale cereale* L.) + forage radish (*Raphanus sativus* L.) + white lupin (*Lupinus albus* L.) and Control (bare soil), with three replicates per treatment, totaling 12 experimental plots. Each plot measured 13.2 m<sup>2</sup> (1.1 × 12 m) with 0.6 m spacing between plots.

Sowing densities were as follows: BO - 100 kg of black oat ha<sup>-1</sup>; BO+CV - 25 kg of black oat ha<sup>-1</sup> and 35 kg of common vetch ha<sup>-1</sup>; Mix - 20 kg of black oat ha<sup>-1</sup>, 25 kg of common vetch ha<sup>-1</sup>, 15 kg of rye ha<sup>-1</sup>, 5 kg of forage radish ha<sup>-1</sup>, and 25 kg of white lupin ha<sup>-1</sup>. Sowing was performed manually by broadcasting, without fertilizer application. When the plants reached full flowering, 109 and 112 days after sowing in 2023 and 2024, respectively, they were managed using a backpack mower. Dry matter production of the cover crops was 6.1 and 6.8 Mg ha<sup>-1</sup> for BO, 4.6 and 7.5 Mg ha<sup>-1</sup> for BO+CV, and 6.6 and 8.7 Mg ha<sup>-1</sup> for Mix in 2023 and 2024, respectively.

Black bean (*Phaseolus vulgaris* L.), cultivar Fepagro Triunfo, was sown over the cover crop residues on October 20, 2023, and October 17, 2024. Each plot was subdivided, with half of the plot receiving management according to technical recommendations for the crop, i.e., inoculation, and N topdressing at the V3/V4. While the other half received the same management, except for N topdressing. Row spacing was 0.5 m, with a planting density of 250,000 plants ha<sup>-1</sup>. Soil fertility correction was performed according to CQFS-RS/SC (2016) recommendations, with applications of 90 kg of

N ha<sup>-1</sup>, 155 kg of P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, and 60 kg of K<sub>2</sub>O ha<sup>-1</sup>. Seed inoculation was carried out using peat-based inoculant containing *Rhizobium tropici* strains SEMIA 4077 and SEMIA 4080, at a rate of 500 g per 500 kg of seed, as recommended for black bean. Nitrogen topdressing with 70 kg of N ha<sup>-1</sup> was applied to half of each plot 23 days after emergence (V4 stage) in both years.

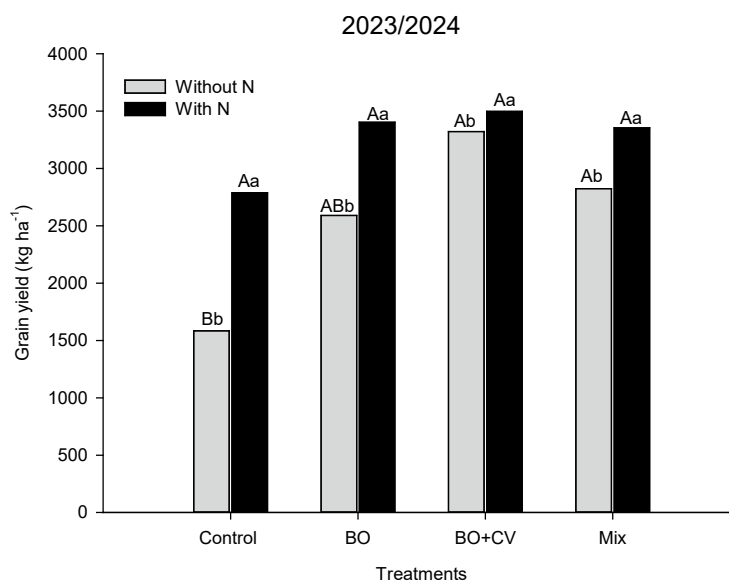
Harvesting and black bean yield component assessments were performed at 96 and 89 days after sowing in the 2023/2024 and 2024/2025 seasons, respectively. At harvest the following variables were measured: plant height (m), measured from the base to the apex using a measuring tape; 1,000-grain weight (g), determined by weighing a sample of 100 grains from each subplot and multiplying by 10; number of pods per plant, counted from 10 randomly selected plants within the usable area of each subplot; number of grains per pod, determined by counting grains from 10 pods of 10 randomly selected plants; grain yield, obtained by harvesting grains from 4.4 m<sup>2</sup> of the usable area of each subplot, with yield corrected to 13% moisture (kg ha<sup>-1</sup>); and final plant density, determined by counting plants in 2 linear meters within each subplot.

Grain yield, yield components, and final plant density data from each growing season were subjected to analysis of variance (ANOVA) using a split-plot design. When significant differences were detected, treatment means were compared using Tukey's test ( $p < 0.05$ ). Statistical analyses were performed using R software (version 2024.04.1).

### 3 RESULTS AND DISCUSSION

Black bean yield in the 2023/2024 growing season was influenced by the interaction between cover crop use and topdressing nitrogen fertilization (Figure 2). Cultivation without nitrogen topdressing after BO+CV and Mix resulted in higher productivity, with an average gain of 3,073.4 kg ha<sup>-1</sup>. The BO treatment yielded 2,590.3 kg ha<sup>-1</sup>, which was statistically similar to BO+CV and Mix, and did not differ from the Control (1,585 kg ha<sup>-1</sup>). These results demonstrate the benefits of incorporating cover crops into production systems. Pacheco *et al.* (2025) evaluated soybean production systems in the Brazilian Cerrado with different cover crop arrangements, including *Pennisetum glaucum*, *Urochloa ruziziensis*, *Zea mays*, and *Crotalaria spectabilis*, observed that soybean yield was higher in all systems with crop cover regardless of the species used compared to systems without cover. Moreover, Yu *et al.* (2025) reported that intercropping or crop rotation systems, especially those involving legumes such as vetch, improve soil fertility, nutrient use efficiency, and plant health. These interactions enhance the performance of subsequent crops, even under low fertilization conditions, due to BNF and improvements in soil structure and microbiota (Lima Filho *et al.*, 2023).

**Figure 2** - Black bean yield ( $\text{kg ha}^{-1}$ ) grown in succession to cover crops with and without topdressing nitrogen fertilization in the 2023/2024 growing season.



Different uppercase letters indicate significant differences among treatments within each N application method, and different lowercase letters indicate differences between N application methods within each treatment, according to Tukey's test ( $p < 0.05$ ).

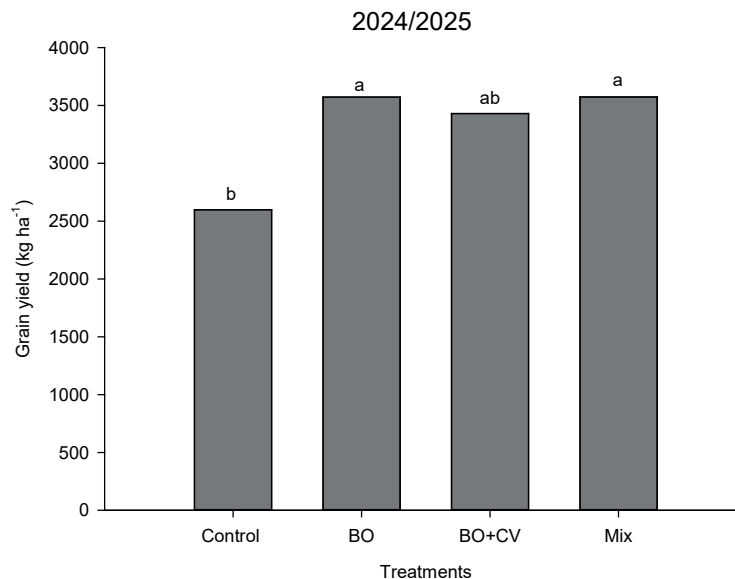
Source: Author's construction.

On the other hand, for this same growing season, nitrogen topdressing did not influence black bean yield in any of the treatments, with an average production of  $3,261 \text{ kg ha}^{-1}$  (Figure 2). The lack of significant yield response to nitrogen fertilization, especially after cover crop cultivation, may be related to improved soil conditions promoted by the preceding crops. According to Aidar & Kluthcouski (2009), in soils with corrected fertility and high input of plant residues, such as those in crop rotation and cover systems, the response to nitrogen fertilization tends to be limited. Additionally, black bean has the ability to perform BNF, which may have met the crop's N requirements, reducing the need for mineral fertilizer supplementation. These results have relevant economic and environmental implications, as nitrogen topdressing represents an increase in production costs without corresponding gains in productivity and, at the same time, indicate that conservation systems based on crop rotation and the use of cover crops can reduce dependence on nitrogen fertilizers, mitigating potential environmental impacts associated with nutrient losses and the degradation of soil and water resources.

In the 2024/2025 growing season, the use of cover crops influenced black bean productivity (Figure 3). Grain yield did not differ between BO and Mix treatments, averaging  $3,573.2 \text{ kg ha}^{-1}$ , which was 22% higher than the Control ( $2,931.7 \text{ kg ha}^{-1}$ ). The BO+CV treatment did not differ significantly from BO, Mix, or Control, with a yield of  $3,430.6 \text{ kg ha}^{-1}$ . This result may be attributed to the availability of essential nutrients for black bean through decomposition and nutrient cycling from the cover crops, such as N, phosphorus (P), potassium (K), and micronutrients. Carvalho *et al.* (2018) and Arf (1994) stated that black bean productivity is closely linked to soil fertility, particularly the

supply of P and K. According to Viola *et al.* (2013), species such as vetch, forage radish, and white lupin can accumulate 103-121 kg of N ha<sup>-1</sup>, 13-20 kg of P ha<sup>-1</sup>, and 250-270 kg of K ha<sup>-1</sup>. Supporting this, Santi *et al.* (2003) demonstrated that black oat, used as a cover crop in the Central Depression of Rio Grande do Sul, Brazil, was capable of accumulating up to 120 kg of N ha<sup>-1</sup> in the aerial biomass, highlighting its potential to contribute to soil nutrient availability.

**Figure 3** - Black bean yield (kg ha<sup>-1</sup>) grown in succession to cover crops in the 2024/2025 growing season (average of treatments with and without topdressing nitrogen fertilization).



Means followed by the same letter do not differ significantly according to Tukey's test ( $p < 0.05$ ).

Source: Author's construction.

Topdressing nitrogen fertilization did not increase black bean yield in the 2024/2025 season, with an average of 3,377.2 kg ha<sup>-1</sup> across treatments (data not shown). This result aligns with findings by Demetrio (2022), who observed no yield differences in black bean with increasing N rates, reporting an average yield of 3,179 kg ha<sup>-1</sup>. Silva Junior *et al.* (2020) also found that nitrogen fertilization did not affect grain yield of early-maturing black bean, regardless of source or application timing. These findings underscore the importance of adopting strategies that maintain productivity while reducing nitrogen inputs, including genetic improvement targeting increased nitrogen use efficiency (NUE), combined with greater plant capacity for nitrogen uptake, assimilation, and utilization (Han *et al.*, 2015). Additionally, the results of the present study reflect the benefits of cover crops in production systems, reducing the dependence on external inputs such as nitrogen fertilizers through sustainable practices like BNF and cover crop use. In a recent study, Telles *et al.* (2025) found that BNF can supply up to 60% of the N requirement of common bean under favorable inoculation and management conditions. Furthermore, the use of cover crops, especially legumes with low C/N ratios, can accumulate significant amounts of N, increase N availability for subsequent crops, and reduce the need for nitrogen fertilization (Adetunji *et al.* 2020).

Yield components of black bean, including plant height, 1,000-grain weight, number of pods per plant, and number of grains per pod were not significantly influenced by cover crop use or nitrogen topdressing in either growing season (Table 1). The only exception was plant height in the 2023/2024 season, where black bean plants grown in succession to cover crops were 20.5% taller than those grown in bare soil. Overall, yield components were minimally affected by cover crop use and nitrogen fertilization. This result is consistent with findings by Arf *et al.* (1999) and Carvalho (2000), who evaluated the effects of crop rotation and green manure on bean productivity and found no influence on agronomic traits.

**Table 1** - Yield components and final plant density of black bean grown in succession to cover crops in the 2023/2024 and 2024/2025 growing seasons (average of treatments with and without topdressing nitrogen fertilization).

Treatment	Height (m)	NPP	NGP	1,000-grain weight (g)	Final plant density (pl. ha <sup>-1</sup> )
<b>2023/2024</b>					
Control	0.7b*	10.7 <sup>ns</sup>	5.7 <sup>ns</sup>	258.0 <sup>ns</sup>	253,333.3 <sup>ns</sup>
BO	0.8a	14.7	5.7	273.7	270,000.0
BO+CV	0.8a	13.9	5.9	275.7	240,000.0
Mix	0.8a	13.7	5.6	271.8	228,333.3
CV (%)	8.5	20.5	8.4	4.9	13.9
<b>2024/2025</b>					
Control	0.8 <sup>ns</sup>	15.9 <sup>ns</sup>	5.9 <sup>ns</sup>	232.5 <sup>ns</sup>	240,000.0 <sup>ns</sup>
BO	0.9	15.1	6.0	232.3	248,333.3
BO+CV	0.9	14.8	6.1	234.5	253,333.3
Mix	0.9	16.7	6.2	232.4	243,333.3
CV (%)	9.9	21.3	8.3	4.4	3.2

NPP: number of pods per plant. NGP: number of grains per pod. ns: not significant. CV: coefficient of variation.

\*Means followed by the same letter do not differ significantly according to Tukey's test ( $p < 0.05$ ).

Source: Author's construction.

Final plant density of black bean was not affected by cover crop treatments or nitrogen topdressing in either growing season. A similar result was reported by Flood & Entz (2018), who found that black bean plant density was not significantly reduced by rye as a preceding crop. Maintaining an adequate plant population, even in systems with soil cover, reinforces the agronomic viability of using cover crops without compromising the stand of the main crop.

## 4 CONCLUSIONS

Winter cover crops, such as black oat alone or in combination with common vetch and mixed species, proved to be an effective strategy for increasing black bean productivity in succession over two growing seasons in Southern Brazil.

Topdressing nitrogen fertilization in black bean resulted in yield increases only in the first year of evaluation (2023/2024), when preceded by cover crop use. The lack of response to nitrogen

fertilization in the second year highlights the potential of cover crops to reduce dependence on external inputs, contributing to the economic and environmental sustainability of production systems.

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