

COVER CROP SYSTEMS AND RESIDUE MANAGEMENT IN WEED CONTROL AND SOYBEAN YIELD

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ABSTRACT:

Management systems, within the context of regenerative agriculture, have been identified as strategies to improve soil health and reduce the use of external inputs. These management systems that use conservationist practices seek to minimize yield losses due to climatic events such as droughts, but the effect of these practices on weed control is poorly documented. The main objective of the research was to evaluate the comparative effect between management systems with cover crops on weed density and soybean yield. This study was developed in the southern region of Brazil in a subtropical climate. The treatments in this study consisted of: conventional system using black oats as a cover crop, no-tillage system using black oats, and no-tillage system with a polyculture of cover crops. The results showed that no-tillage with the use of forage radish followed by a second sowing with several species of cover crops (polyculture) was efficient in minimizing the density and height of *Conyza bonariensis* and *Solanum americanum*. The suppression of these two weed species was associated with the greater production of dry matter from these cover crops and, consequently, resulted in a greater grain yield of soybeans grown in succession.

Keywords: Regenerative agriculture, no-till farming, weed control, soybean productivity.

SISTEMAS DE PLANTAS DE COBERTURA E MANEJO DE RESÍDUOS NO CONTROLE DE PLANTAS DANINHAS E NA PRODUTIVIDADE DA SOJA

RESUMO:

Sistemas de manejo, no contexto da agricultura regenerativa, têm sido identificados como estratégias para melhorar a saúde do solo e reduzir o uso de insumos externos. Tais sistemas, que utilizam práticas conservacionistas, buscam minimizar as perdas de produtividade decorrentes de eventos climáticos, como secas, mas o efeito dessas práticas no controle de plantas daninhas ainda é pouco documentado. O objetivo principal da pesquisa foi avaliar o efeito comparativo entre sistemas de manejo com plantas de cobertura sobre a densidade de plantas daninhas e a produtividade da soja. O estudo foi conduzido na região Sul do Brasil, sob clima subtropical. Os tratamentos consistiram em: sistema convencional com aveia-preta como planta de cobertura, sistema de plantio direto com aveia-preta e sistema de plantio direto com policultivo de plantas de cobertura. Os resultados mostraram que o plantio direto com o uso de nabo-forrageiro, seguido de uma segunda semeadura com diversas espécies de plantas de cobertura (policultivo), foi eficiente em minimizar a densidade e a altura de *Conyza bonariensis* e *Solanum americanum*. A supressão dessas duas espécies de plantas daninhas deveu-se à maior produção de matéria seca pelas plantas de cobertura, o que, consequentemente, resultou em maior produtividade de grãos de soja cultivada em sucessão.

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Palavras-chave: Agricultura regenerativa, Plantio direto, Controle de plantas daninhas, Produtividade da soja

INTRODUCTION

Food production is closely linked to food security and sustainable grain production. Brazil is one of the world's largest agricultural producers and still has enormous potential for future growth (Dias *et al.*, 2016). Thus, several global challenges have been identified, such as increasing production efficiency, recovering degraded agricultural areas, reducing the use of pesticides, and preserving soil and water. In this context, it is essential to understand regenerative management practices as solutions that contribute to achieving balance and sustainability in agriculture (Purvis *et al.*, 2019).

One of the main growing challenges in agriculture, particularly in tropical and subtropical regions, is weed control (Rew *et al.*, 2005; Walker *et al.*, 2011). In particular, the species *Conyza bonariensis* of the Asteraceae family, which is characterized by its strong competitiveness and high dispersal potential (Diez de Ulzurrun *et al.*, 2020; Kaspary *et al.*, 2023), has been particularly challenging to manage in Brazilian soybean production. Since the 2005 harvest, these biotypes have shown resistance to glyphosate, the main herbicide used in soybean production (Vargas *et al.*, 2007).

Currently, biotypes of *Conyza bonariensis*, commonly known as hairy fleabane, have shown resistance to herbicides with different mechanisms of action, including EPSPS (5-enolpyruvylshikimate-3-phosphate synthase), ALS, Photosystems I and II, and synthetic auxins (Heap, 2025). The main factors associated with *Conyza bonariensis* resistance in crops include production systems characterized by low residue input to the soil surface, lack of cover crop rotation, and long time intervals between desiccation and soybean planting.

This weed is a positive photoblastic plant and alternating temperatures stimulate its seed germination (Vidal *et al.*, 2007). In this sense, greater light exposure at the soil surface favors weed emergence. As a result, weed control becomes highly dependent on herbicide use, which increases production costs and economic risks (Lorenzetti *et al.*, 2025).

Similarly, the species *Solanum americanum* has drawn attention in various regions of the world due to the recurring damage it causes to cereal, vegetable, and pasture crops (Schuster *et al.*, 2016; Saha and Datta, 2017). Furthermore, it has demonstrated resistance to chemical control agents,

mainly due to its morphological characteristics and high adaptability to diverse ecosystems. In this context, soil cover can serve as a key strategy to prevent the species' germination and emergence, as it influences incident solar radiation at the soil surface, water balance, and soil temperature fluctuations (Alonso-Ayuso *et al.*, 2018; Franceschetti *et al.*, 2023).

The use of cover crops in a production environment with an already well-established planting system can provide ecosystem services such as soil cover, weed suppression and moisture conservation, with positive impacts on food supply and the environment. In this context, three principles are associated with conservation agriculture: (a) minimizing physical disturbances caused by mechanical operations on the soil surface, (b) maintaining diverse vegetation on the soil surface for as long as possible during the year, ensuring soil protection against the impact of rain and incident solar radiation while inhibiting weed emergence; and (c) increasing species diversification over time and space through crop rotation and the introduction of species biodiversity during the same cycle (Kassam *et al.*, 2009; Kassam *et al.*, 2019; Passinato *et al.*, 2021).

Recent studies investigating key production regions in Brazil, particularly in the state of Rio Grande do Sul, have demonstrated that regenerative management systems offer greater resilience in terms of both production stability and soil health, with crop rotation and the introduction of cover crops serving as key factors in achieving these benefits (Bonini Pires *et al.*, 2020; Passinato *et al.*, 2021; Souza *et al.*, 2024).

This study sought to evaluate the impact of management systems with the addition of high volumes of biomass and species biodiversity on weed control. The main objective of the research was to evaluate the effect of different vegetation cover systems with different levels of diversity and biomass input on weed suppression and soybean yield, with particular emphasis on the suppression of *Conyza bonariensis* and *Solanum americanum*.

MATERIAL AND METHODS

Study site, environmental conditions and experimental design

The research began in April 2022, in the municipality of Frederico Westphalen, Rio Grande do Sul, Brazil (27° 23' 51" S and 53° 35' 19" W,

elevation: 490 m), with an average annual precipitation of 1881.00 mm, an average temperature of 19.1 °C and a humid subtropical Cfa climate according to the Köppen classification. The precipitation and average temperature data during the study were collected from the National Institute of Meteorology (INMET) meteorological station located at the Federal University of Santa Maria, Frederico Westphalen campus (Figure 1).

The soil of the site is classified as Dystrophic Red Latosol (Oxisol) (Santos *et al.*, 2018), and presents the following chemical characteristics in the 0–10 cm layer: clay 790 g kg⁻¹, pH (H₂O) 5.0; P 5.1 mg dm³; K 172 mg dm³; Ca 6.3 cmol_c dm³; Mg 3 cmol_c dm³; Al 0.2 cmol_c dm³; base saturation in the CTC 66.6%; aluminum saturation in the CTC 1.6%; and soil organic matter 2.8%. Before the implementation of the experiment, the area had been managed under a long-term no-tillage system.

The experiment began in April 2022, when three management systems were implemented, allocated in main blocks measuring 45 m x 18 m, with a usable area of 810 m² for each system. The management systems studied were: (T1) conventional soil preparation system and the sowing of black oats (*Avena strigosa* S.), (T2) no-tillage

system with the sowing of black oats, and (T3) no-tillage system with the sowing of autumn forage radish (*Raphanus sativus* L.), followed by the sowing of a winter polyculture composed of different cover crops. The polyculture consisted of 12.5% black oats, 14.44% white oats (*Avena sativa*), 22.22% rye (*Secale cereale*), 12.5% common vetch (*Vicia sativa* L.), 12.5% hairy vetch (*Vicia bithynica* L.), 11.11% white lupin (*Lupinus albus*), 2.22% forage radish, and 12.5% turnip (*Brassica rapa* L.).

In the conventional system, aiming to improve the soil profile, soil preparation was carried out to a depth of 40 cm. Soil mobilization began with scarification, followed by plowing and harrowing. All management systems received 3 Mg ha⁻¹ of dolomitic limestone with a PRNT of 60.7%, a CaO concentration of 26% and MgO of 13%. Cover crops were sown on 01/04/2022, with a winter seeder at a spacing of 0.17 m, with the application of 200 kg ha⁻¹ of P₂O₅. In T3, the polyculture was sown over the green biomass of forage radish on 06/16/2022. The seed densities used were: T1 black oats (80 kg ha⁻¹), T2 black oats (80 kg ha⁻¹), and T3 (15 kg ha⁻¹ forage radish/ 90 kg ha⁻¹ polyculture).

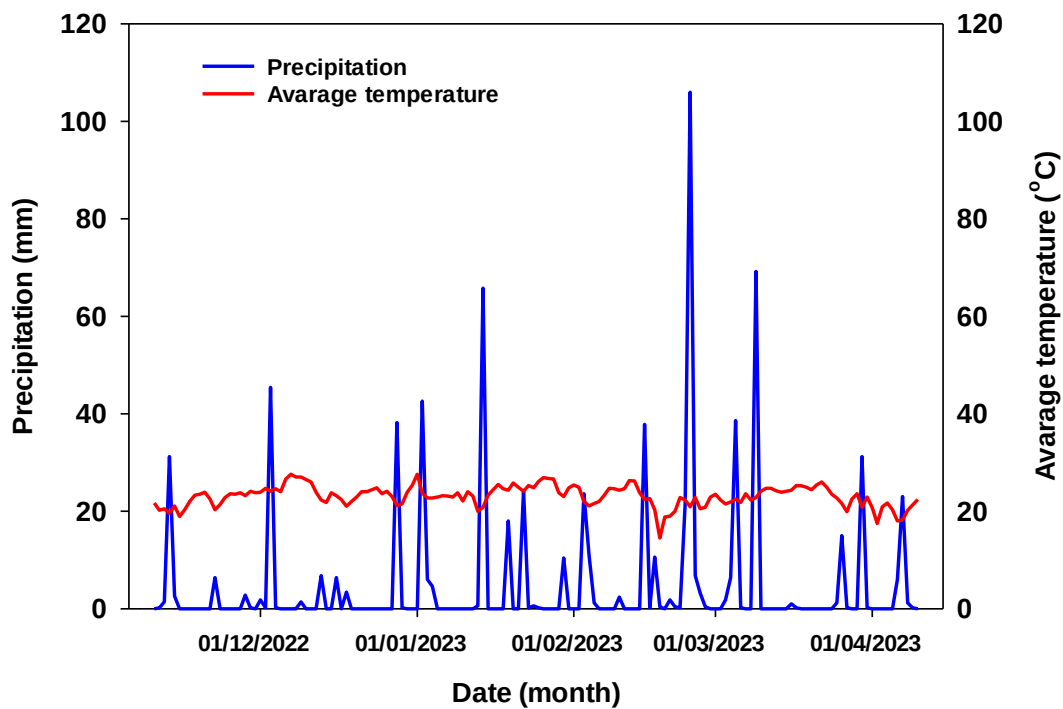


Figure 1. Daily distribution of precipitation and average temperature. Frederico Westphalen – RS, Brazil, 2022/2023, growing season.

Dry matter of cover crops

The dry matter production of cover crops was evaluated at full flowering and estimated over a useful area of 0.25 m². The systems with black oats (T1 and T2) were evaluated at 96 days of the cycle, whereas in T3, forage radish was evaluated at 68 days and the polyculture at 120 days. The samples were dried in an oven with air circulation at a temperature of 60 °C until the weight stabilized

Cover crop desiccation was performed on October 28 (12 days before soybean sowing), using a mixture of saflufenacil, glyphosate, and clethodim in management systems T1 and T2 (black oat), and on November 9 (1 day before soybean sowing), using saflufenacil and clethodim in system T3 (polyculture).

Weed assessment

Weed density, height and total dry matter were assessed at the end of the cover crop cycle before herbicide application. Twenty-four random points were assessed in each management system, over a useful area of 0.250 m² per sample. The weed density of *Conyza bonariensis* and *Solanum americanum* was assessed by identifying and counting the species. Height was subdivided into three levels: level 1 (<10 cm), level 2 (10 to 20 cm) and level 3 (>20 cm). Dry matter and infestation level were assessed by adding *Conyza bonariensis*, *Solanum americanum* and other species present. These samples were collected and dried in an oven with forced air circulation at a temperature of 60 °C

until the sample weight stabilized. Soil coverage by weeds was measured using the Canopeo application, with readings taken between the soybean rows, using the vegetation index expressed in percentage (%) over a useful area of 0.220 m². This assessment was carried out after soybean emergence at the V3-V4 vegetative stage, before post-emergence herbicide management.

Soybean sowing was carried out on 11/10/2022 (Figure 2), using the Monsoy 5947 cultivar and a base fertilization of 250 kg ha⁻¹ with a formulation of N (2%), P (23%) and K (23%). The final plant stand was 8.9 plants m⁻¹ (conventional black oat system), 7.6 plants m⁻¹ (no-tillage black oat system) and 7.4 plants m⁻¹ (no-tillage polyculture system). Regarding the phytosanitary management of soybeans, the same management was used in all management systems. Soybean harvesting was performed manually on April 10, 2023, with three subsamples per management system and a net plot area of 2.7 m²; after weighing the samples, grain moisture was adjusted to 13%.

Herbicide management in post-emergence of soybeans was carried out only in systems T1 and T2 (Glyphosate) + (Haloxypop-P-methyl).

Statistical analysis

The data were subjected to analysis of variance (ANOVA) and compared by the Tukey test ($p < 0.05$). All statistical analyses were performed using the Sisvar statistical program, version 5.3 (Ferreira 2014).



No-till system (black oats)

No-till system (polyculture)

Figure 2. Cover crops close to the time of soybean sowing, 11/04/2022. Frederico Westphalen – RS, Brazil.

RESULTS AND DISCUSSION

The level of infestation of *Conyza bonariensis* for the density variable did not differ statistically among management systems (Figure 3A). The

management system using black oats as a cover crop had the highest average densities of *Conyza bonariensis*, 27.1 no-till oat and 8.3 plants m⁻² for the and conventional oat systems. In the no-till polyculture system, the lowest average density of 2.3

plants m^{-2} was observed, with a reduction of 91.51 and 72.28% in relation to the no-till oat and conventional oat systems.

The level of infestation of *Conyza bonariensis* had a very similar behavior in terms of both density and height in the management systems studied. The conventional and no-till systems, in which black oats were used as the cover crop, presented very similar results, both because the same plant species was used and because of the cycle during which these cover crops remained on the soil surface. In a study evaluating different winter cover crops, the authors found a positive relationship between species with greater potential for dry matter production and a reduction in the density of *Conyza bonariensis* (Lamego *et al.*, 2013). The same authors highlight that vetch is one of the best alternatives for soil cover to control *Conyza bonariensis* until pre-sowing desiccation of the soybean crop. Vetch and forage radish are also efficient in controlling *Conyza*

bonariensis up to 12 and 27 days after soybean emergence, respectively

The height of *Conyza bonariensis* was statistically higher in the no-tillage oat and conventional oat management systems, with average values of 19.5 and 8.7 cm, respectively (Figure 3B). The no-tillage system with polyculture had the lowest height, 3.3 cm. The density and height variables of *Conyza bonariensis* demonstrated that the higher the density, the higher the height of this weed.

In a study of rye as a winter cover crop, Pittman *et al.* (2019) also reported an efficient reduction of 88% to 96% in the incidence of *Conyza bonariensis*. In addition, the authors reinforced that treatments with cover crops performed as well as or better than residual herbicides applied in the fall. In this sense, the use of polyculture in no-till planting deserves special attention as it allows for a longer cycle of cover crops, keeping the soil protected for longer (Souza *et al.*, 2024).

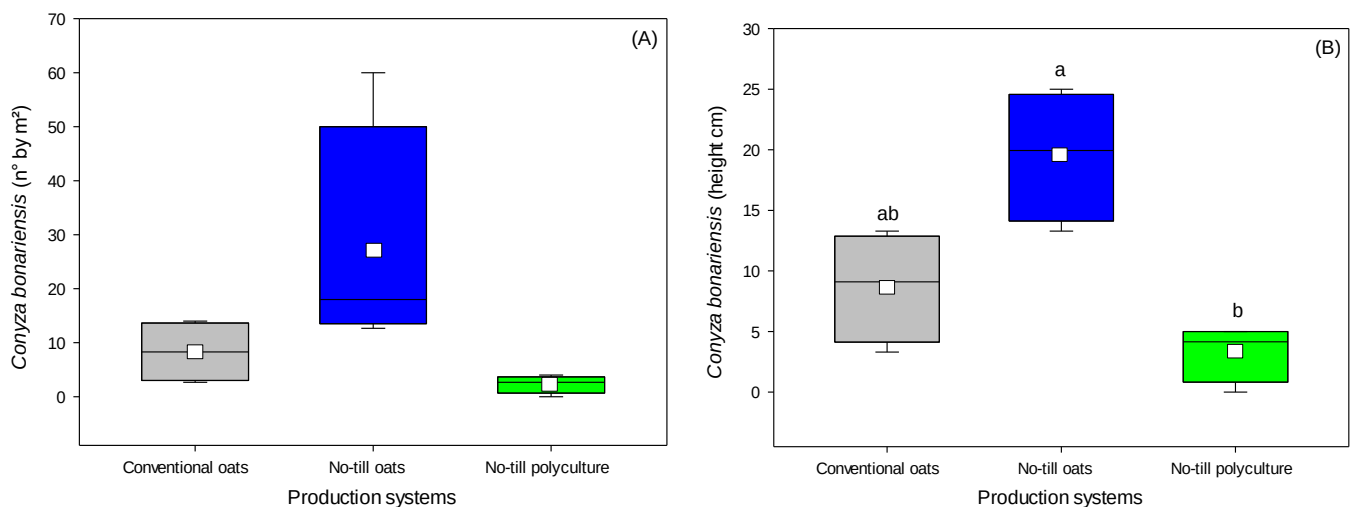


Figure 3. (A) Density and (B) height of *Conyza bonariensis* in different management systems. The lower and upper hinges correspond to the first and third quartiles (the 25th and 75th percentiles). The upper whisker extends from the hinge to the highest value and the lower one to the lowest value found. The letters refer to the statistical separation between the management systems according to Tukey's test ($p < 0.05$). Frederico Westphalen, Rio Grande do Sul, Brazil, 2022/2023 growing season.

Positive photoblastic species such as *Conyza bonariensis* require light to enable seed germination. In the conventional system where mechanical soil preparation was carried out prior to the establishment of the cover crop, the viability of *Conyza bonariensis* seeds may be reduced to some extent by incorporating them into the soil at greater depths compared to the direct planting of black oats, where the soil remains

under minimal surface disturbance. In this sense, a study by Bhowmik & Bekech (1993) showed a positive correlation between the reduction in the viability of *Conyza bonariensis* seeds and physical soil disturbance when comparing the direct planting and conventional systems.

For *Solanum americanum*, no significant difference was observed in infestation levels among

management systems (Figure 4A), with averages of 3.6, 2.3 and 0.3 plants m^{-2} for the conventional oat, no-tillage oat and polyculture systems, respectively. Regarding height (Figure 4B), the conventional oat system (12.8 cm) was statistically superior to the polyculture system (0.8 cm) and did not differ

significantly from the no-tillage system (4.9 cm). Again, as observed for *Conyza bonariensis*, a similar relationship between the density and height variables was observed for *Solanum americanum*.

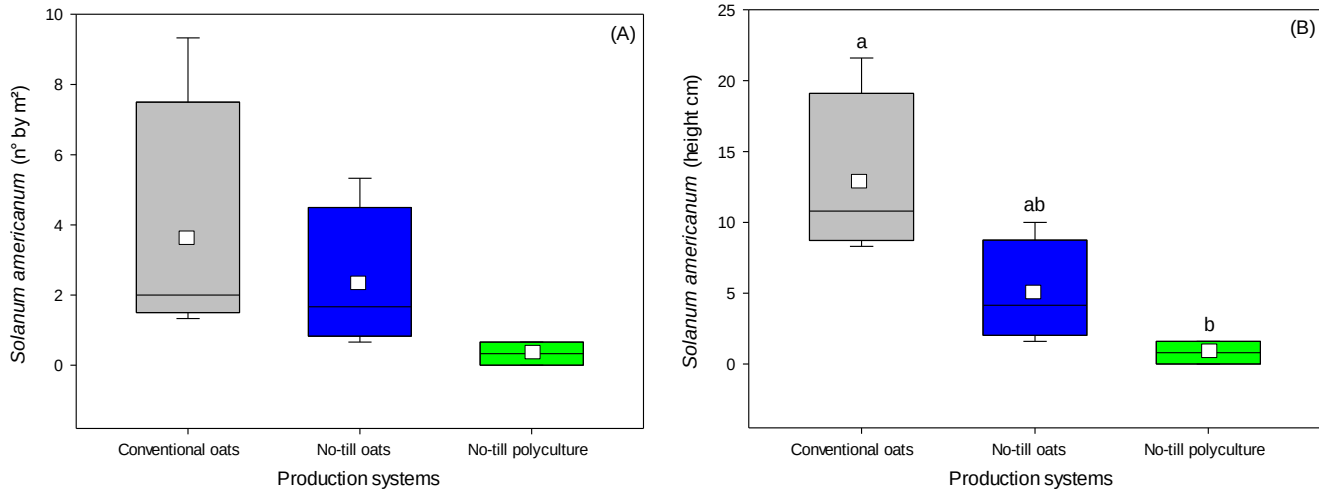


Figure 4. (A) Density and (B) height of *Solanum americanum* in different management systems. The lower and upper hinges correspond to the first and third quartiles (the 25th and 75th percentiles). The upper whisker extends from the hinge to the highest value and the lower one to the lowest value found. The letters refer to the statistical separation between the management systems according to Tukey's test ($p < 0.05$). Frederico Westphalen, Rio Grande do Sul, Brazil, 2022/2023 growing season

For *Solanum americanum*, higher levels of density and height were observed in the conventional black oat system, unlike those observed for the species *Conyza bonariensis*. Therefore, physical soil mobilization combined with the use of a single cover crop was not sufficiently effective in alleviating the pressure of this invasive species. In contrast, minimal physical disturbance of the soil, such as direct planting associated with species diversity in polyculture, was effective in suppressing the infestation of *Solanum americanum* during the fall and winter seasons. These results corroborate those found by Franceschetti *et al.* (2023), who highlight that the degree of soil cover had a great effect on the percentage of *Solanum americanum* in both types of cover, *Avena sativa* in the winter season and *Glycine max* in the summer.

In Figure 5A, it is possible to observe that there is a relationship between the dry matter production of cover crops and the dry matter of weeds in each management system. The conventional oat and no-tillage oat systems had the highest averages of weed dry matter production, 599.4 and 486.4 $kg\ ha^{-1}$ (Figure 5A) and consequently the lowest averages in

dry matter production by each cover crop, 6400 and 6200 $kg\ ha^{-1}$ (Figure 5B). The no-tillage polyculture system had the highest cover crop dry matter production, 18733 $kg\ ha^{-1}$ (Figure 5B), with values up to 192.7 and 202.14% higher than those of the conventional oat and no-tillage oat systems and a lower weed dry matter production, 15 $kg\ ha^{-1}$ (Figure 5A).

The percentage (%) of vegetation did not differ among the management systems (Figure 5C), with averages of 27.4, 11.7 and 0.8% in the conventional oat, no-tillage oat and no-tillage polyculture systems, respectively.

The use of polyculture as a cover crop combined with the no-tillage system was essential to reduce weed pressure from species such as *Conyza bonariensis* and *Solanum americanum*. In addition, the low density identified in this management system was characterized by short plants (< 3.4 cm), which were consequently easier to control chemically, demonstrating the possibility of high control efficiency when multiple cover species are combined and associated with integrated management. These results are mainly due to two factors: greater straw

production in the system (dry matter on the soil surface) and the allelopathic effect of aromatic extracts (Almeida, 1988; Calegari *et al.*, 2020; Teasdale *et al.*, 2007), released during their

development through the roots, and at the end of their cycle through straw decomposition (Almeida, 1985; Panchal *et al.*, 2022).

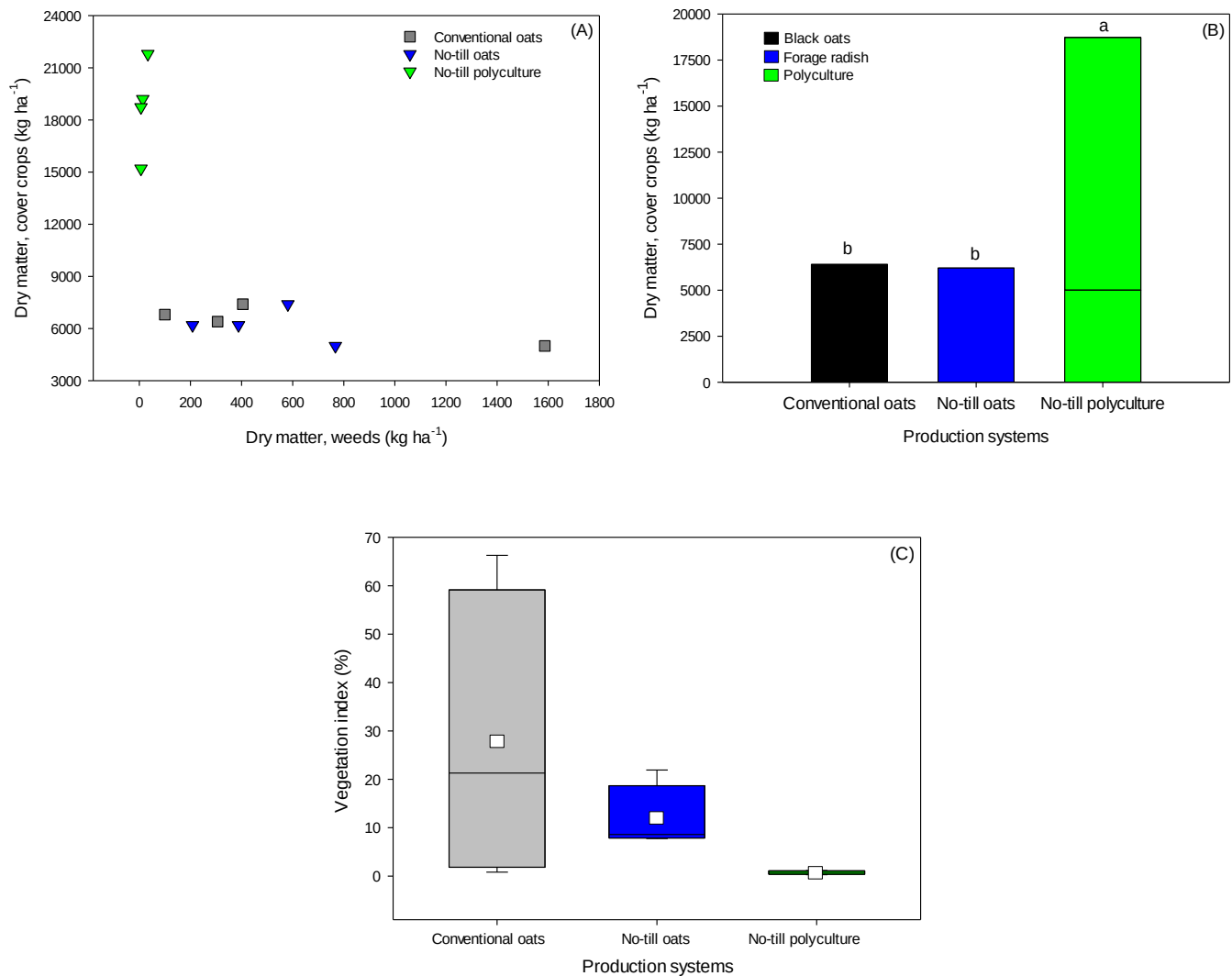


Figure 5. (A) Relationship between dry matter production by cover crops and dry matter production by weeds. (B) Total dry matter production by cover crops. (C) Percentage (%) of weed vegetation remaining post-emergence in different management systems. The lower and upper hinges correspond to the first and third quartiles (the 25th and 75th percentiles). The upper whisker extends from the hinge to the highest value and the lower one to the lowest value found. The letters refer to the statistical separation among the management systems according to Tukey's test ($p < 0.05$). Frederico Westphalen, Rio Grande do Sul, Brazil, 2022/2023 growing season.

Regarding the final soybean grain yield, significant differences were observed among the management systems (Figure 6A). The conventional and no-tillage oat systems had the lowest yields, at 3588 and 3656 kg ha⁻¹, respectively. In contrast, the no-tillage polyculture system had the highest yield, at 4885 kg ha⁻¹, representing increases of 36.14 and

33.61% compared with the conventional and no-tillage oat systems, respectively.

In this study, the results provide a different perspective on the no-till system commonly adopted in Rio Grande do Sul crops. Simply producing straw in the system, as observed with black oats in both no-till and conventional systems, is not sufficient. Instead, it is necessary to consider strategies that

enable the production of high volumes of dry matter ($> 7 \text{ tons ha}^{-1}$) during the fall/winter. This approach contributes to the drastic reduction of weed development both during the off-season period and the first phenological stages of the soybean crop, especially the vegetative stages V3-V4.

Finally, grain yield increased when the no-tillage system was combined with conservation/regenerative practices, such as forage radish during the fall season, followed by winter polyculture directly seeded over still active/green cover crops. This strategy is similar to the one adopted in the study by Lawley *et al.* (2011). The authors report that the use of forage radish provided complete suppression of winter annual weeds in the fall and early spring, but this suppression did not persist in the subsequent growing season. Therefore, it is essential to combine a second sowing of cover crops or long-cycle species during the same crop.

When analyzing the different systems, it was observed that the variability of both weeds, *Conyza bonariensis* and *Solanum americanum*, as well as

soybean grain yield, was remarkably similar when black oats were used as a cover crop in no-tillage and conventional planting systems. This indicates a need for producers to understand the short, medium, and long-term strategies that may contribute to increasing crop yield.

These strategies undoubtedly involve the constant use of cover crops, mainly by combining several species and/or using polycultures, thereby enabling soil improvement, particularly through the introduction of vetch in the southern region of Brazil and rye in other regions around the world (Antichi *et al.*, 2022; Calegari *et al.*, 2020; Pott *et al.*, 2020; Pott *et al.*, 2021; Rushing *et al.*, 2023; Souza *et al.*, 2024). This study reinforces the importance of soil conservation and regenerative practices, such as permanent cover, minimal disturbance, plant diversity, and sowing on green cover crops, as important strategies for achieving sustainable agriculture.

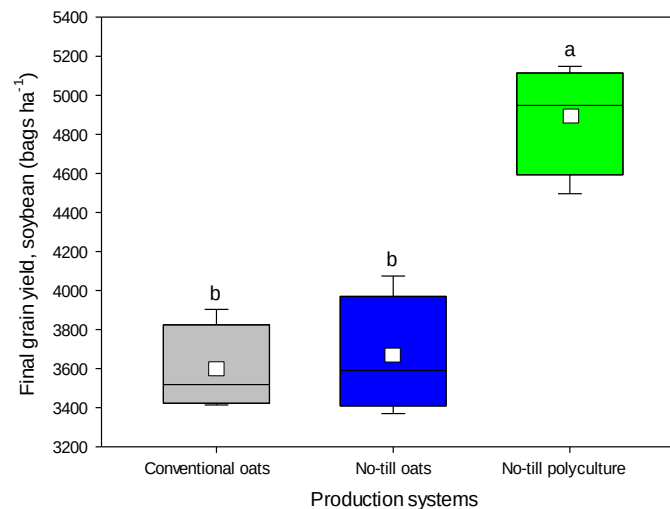


Figure 6. Grain productivity of soybean crops in different management systems. The lower and upper hinges correspond to the first and third quartiles (25th and 75th percentiles). The upper whisker extends from the hinge to the highest value and the lower one to the lowest value found. The letters refer to the statistical separation among the management systems according to Tukey's test ($p < 0.05$). Frederico Westphalen, Rio Grande do Sul, Brazil, 2022/2023 growing season

CONCLUSION

The adoption of the no-till system with winter polyculture demonstrated high efficiency in suppressing weeds, significantly reducing the density

and height of these plants. In addition, this conservation strategy resulted in greater soybean yield, highlighting the fundamental role of the functional diversity of cover crops in building more resilient and productive agricultural systems.

The results indicate that the use of black oats alone, even under no-tillage, may not be sufficient for effective weed management, emphasizing the importance of timing and diversity of cover crops. Therefore, strategies that promote permanent cover, minimal soil disturbance and high plant diversity should be prioritized for the advancement of regenerative systems in southern Brazil and other subtropical regions.

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