Acta Scientiarum
http://periodicos.uem.br/ojs
ISSN on-line: 1807-8621
https://doi.org/10.4025/actasciagron.v48i1.75936
CROP PRODUCTION

Monoculture and winter cover crop mixtures and their decomposition in a subtropical environment

Leonardo Sari Stefanello[1], Guilherme Bergeijer da Rosa[2*], Anderson César Ramos Marques[3], Anderson Crestani Pereira[1], Emilso Damm dos Santos[1], Fernanda Maria Mieth[1], Vanderlei Both[1] and Diego Nicolau Follmann[1]

[1]Departamento de Fitotecnia, Universidade Federal de Santa Maria, Santa Maria, Rio Grande do Sul, Brazil. [2]Subdivisão de Gestão de Laboratórios, Universidade Federal de Santa Maria, Rua Sete de Setembro, s/n, 98400-000, Frederico Westphalen, Rio Grande do Sul, Brazil. [3]Departamento de Biologia, Universidade Federal de Santa Maria, Santa Maria, Rio Grande do Sul, Brazil. *Author for correspondence. E-mail: eng.guilhermerosa@gmail.com

ABSTRACT. The use of cover crops during the winter period is the foundation of the no-till system and provides physical, chemical, and biological benefits to the soil. A high biomass input from cover crops and benefits related to nutrient cycling also enhance the presence of beneficial soil microorganisms. Thus, this study aimed to evaluate dry matter phytomass production, the soil coverage curve with cover crops, and the decomposition curve of dry matter phytomass in monoculture and cover crop mixtures in a subtropical environment. The following cover crop treatments were evaluated during the winters of 2022 and 2023 using a randomized block experimental design: black oat, rye, common vetch, forage radish, black oat + common vetch, black oat + forage radish, black oat + common vetch + forage radish, rye + common vetch, rye + forage radish, and rye + common vetch + forage radish. Dry matter phytomass production, soil coverage, and dry matter phytomass decomposition were measured using the litter bag method. Black oat and forage radish in monoculture stood out for their dry matter phytomass production, and forage radish excelled in mixed treatments, presenting values exceeding 50% of the composition in all cases. Soil coverage was adequate for black oat, rye, common vetch, and forage radish in monoculture and their intercropping systems. After 150 days of decomposition, black oat and rye exhibited the lowest decomposition rates, and the cover crop mixtures showed intermediate decomposition rates, confirming their suitability as autumn/winter cover crops in subtropical environments.

Keywords: green manure; nutrient cycling; phytomass; regenerative agriculture; soil conservation; species intercropping.

Received on February 28, 2025.
Accepted on October 11, 2025.

Introduction

For the 2023/2024 season, soybean and maize production in Brazil exceeded 65 million hectares, with 45 million hectares cultivated with soybean and 20 million hectares with maize (Companhia Nacional de Abastecimento [CONAB], 2024). Rio Grande do Sul (southernmost Brazil) utilizes over 6 million hectares for soybean production and 800,000 hectares for maize, and approximately 1.3 million hectares are cultivated with wheat during winter (Companhia Nacional de Abastecimento, 2024). The remaining area is often underutilized by extensive livestock farming or left fallow, which can increase weed emergence and cause non-uniform soil coverage. When maize is planned as the primary crop in Rio Grande do Sul, cover crop introduction, either as a monoculture or intercropping system, is typically considered in advance. Some of the main cover crops used in southern Brazilian systems include black oat (*Avena strigosa* Schreb), rye (*Secale cereale* L.), forage radish (*Raphanus sativus* L.), and common vetch (*Vicia sativa* L.). According to Silva et al. (2021), species selection should consider the intended purpose of cultivation, with grasses and legumes being the most prominent choices.

Each species offers distinct benefits and limitations, increasing interest in cover crop mixtures (intercropping with two or more species). Pessotto et al. (2016) found that cover crops improved the soil structure, resulting in benefits for subsequent crops. Introducing cover crops into crop rotation systems enhances soil fertility and organic matter levels, contributing to agricultural sustainability (Rosa et al., 2017). Moreover, cover crops influence soil biological properties, increasing microbial diversity and suppressing soilborne pathogens and weeds (Almeida et al., 2016; Pittman et al., 2020).

Cover crops primarily function to shield the soil from the kinetic energy of raindrops during their growth and after desiccation, and their integration into cropping systems enhances soil protection and improves the soil's physical parameters. According to Basche and DeLonge (2019), soil macropores, which affect aeration and water infiltration, are key physical attributes improved by cover crops. Cover crops also reduce the leaching of soil carbon (C) and other nutrients (Singh et al., 2021).

A critical characteristic of cover crops is their rapid establishment. Rapid canopy closure decreases weed emergence and minimizes the exposure of soil to the direct impact of rainfall (Wayman et al., 2017). Such tools as the normalized difference vegetation index (NDVI) can be used to measure the canopy soil coverage rate (Asadi et al., 2019; Borgogno-Mondino et al., 2018).

Grasses in monoculture or intercropping systems exhibit rapid growth and offer greater soil protection potential due to their higher carbon-to-nitrogen (C/N) ratio compared to crucifers and legumes. This enables grass-based intercropping systems to maintain plant residues on the soil surface for extended periods (Ziech et al., 2015). Identifying optimal species mixtures to maximize both biomass production and ecosystem interactions remains a challenge, as different species combinations confer distinct ecosystem functions (Allan et al., 2015).

Given the significance of cover crops, further studies focusing on monoculture and cover crop mixtures and the decomposition of dry matter phytomass are necessary to understand their development and coverage capacity. Therefore, this study aimed to evaluate dry matter phytomass production, the soil coverage curve of cover crops, and the decomposition curve of dry matter phytomass in monoculture and cover crop mixtures in a subtropical environment.

Material and methods

The experiments were conducted in 2022 and 2023 within the experimental area of the Department of Crop Science at the Federal University of Santa Maria, located in Santa Maria, Rio Grande do Sul State, Brazil (29°43'28 S, 53°43'41" W). The soil is classified as a dystrophic arenic Red Argisol (Santos et al., 2018). According to the Köppen classification, the climate is Cfa, a humid subtropical climate characterized by rainy and warm conditions (Alvares et al., 2013).

Four species were sown in monoculture and mixed cover crop systems on April 17, 2022, and April 5, 2023: black oat (BO), rye (R), common vetch (CV), and forage radish (FR). This resulted in 10 treatments: T1 = BO; T2 = R; T3 = CV; T4 = FR; T5 = BO (50%) + CV (50%); T6 = BO (50%) + FR (50%); T7 = BO (50%) + FR (25%) + CV (25%); T8 = R (50%) + CV (50%); T9 = R (50%) + FR (50%); T10 = R (50%) + FR (25%) + CV (25%). In the cover crop mixtures, at least 50% grass was prioritized to maintain an optimal C/N ratio.

The experimental plots were 1.8 m wide and 3.0 m long, totaling 5.4 m^2. The experiment was setup in a randomized complete block design, with four replications per treatment. The cover crop seeding rates were as follows: BO = 80 kg ha^{-1}; R = 50 kg ha^{-1}; CV = 50 kg ha^{-1} (Fontaneli et al., 2012); and FR = 15 kg ha^{-1} (Cargnelutti Filho et al., 2022). For the mixture treatments, seed quantities varied based on their proportions, referencing the monoculture seeding rate, with treatments T5–T10 following the proportional percentage of the reference values from T1 to T4.

During the experimental period, soil coverage was assessed using the NDVI system with a GreenSeeker® device. NDVI values ranged from 0.0 to 1.0, with higher values indicating greater soil coverage. Four and five measurements were taken in 2022 (23, 41, 59, and 95 days after emergence) and 2023 (35, 50, 65, 80, and 95 days after emergence), respectively.

Green biomass was quantified at anthesis for BO and R, the end of flowering for FR, and the beginning of flowering for CV. A 2-m^2 sample was collected from each plot, and a representative subsample was dried in a forced-air oven at 65°C until a constant weight was reached and then used to estimate the total dry matter phytomass production. Samples were collected on August 29, 2022, and August 13, 2023.

The decomposition rate of the cover crop residues was evaluated using the litter bag method, with 2-mm mesh bags measuring 25 × 20 cm (Santos et al., 2024). The dry matter phytomass equivalent to the biomass produced in each treatment was placed in the litter bags, maintaining a 500 cm^2 area corresponding to the litter bag dimensions, and distributed in four replications with five collection times (30, 60, 90, 120, and 150 days after soil exposure). The litter bags were sampled at each timepoint (30, 60, 90, 120, and 150 days), and the contents were dried in a forced-air oven at 65°C until a constant weight was achieved. The remaining dry matter phytomass was then recorded.

The daily average temperature data and recorded rainfall volumes for the experimental period in 2022 and 2023 were obtained from the National Institute of Meteorology (INMET) meteorological station at the Federal University of Santa Maria (Figure 1).

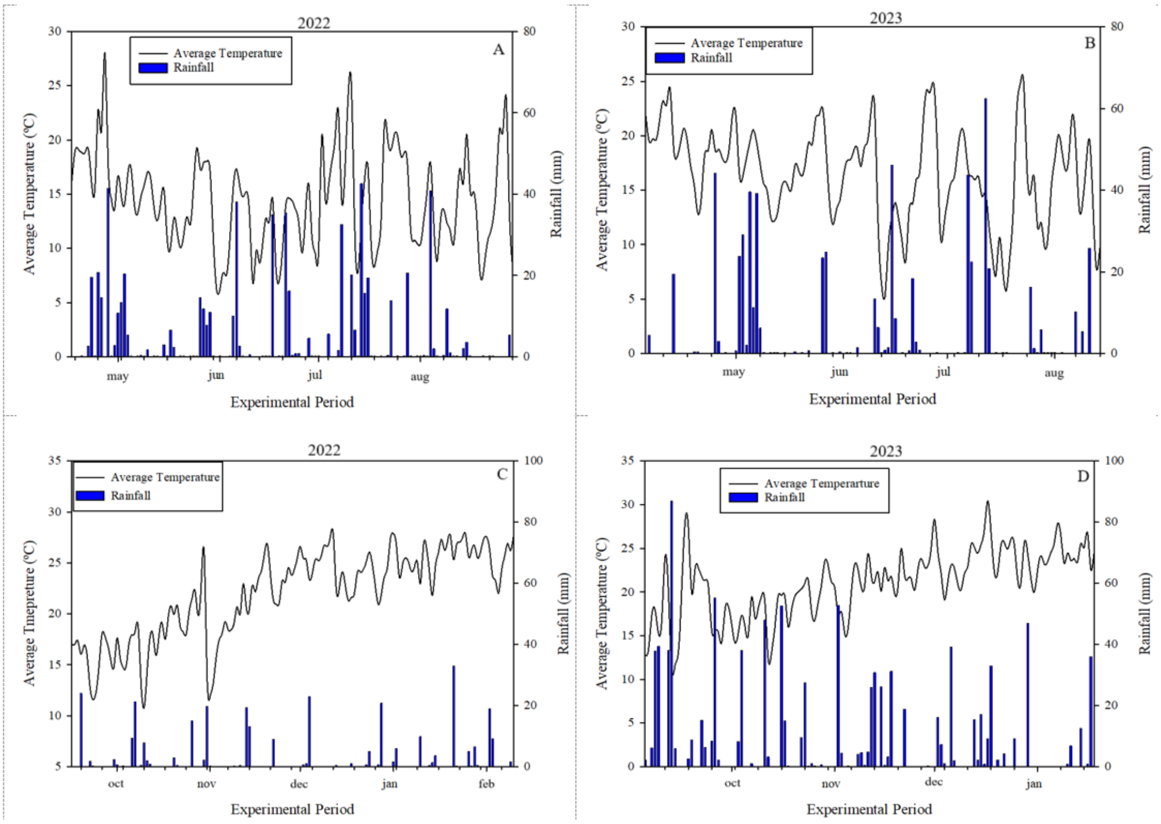

Figure 1. Rainfall and daily average air temperature during the cover crop development period (A and B) and cover crop decomposition rate (C and D) in 2022 and 2023, respectively.

The collected variables were subjected to a joint analysis of variance across years to identify differences between treatments. Subsequently, means were grouped using the Scott–Knott test at a 5% probability of error using R software version 4.3.3 (R Core Team, 2024).

Results and discussion

A total rainfall of 453 mm was recorded throughout the cover crop period in 2022, and 592.6 mm was recorded in 2023 (Figure 1). This resulted in an average daily rainfall of 3.38 mm in 2022 and 4.55 mm in 2023. Although the occurrence of these rainfall volumes was not uniform, periods of water deficit were not observed during cover crop development.

When comparing the two years, dry matter phytomass production was higher in 2023 for 7 of the 10 treatments, with significant differences ($p \leq 0.05$) observed in BO and CV monocultures and in the R + CV + FR mixture (Table 1). Ruis et al. (2019) found that, in association with temperature, biomass production is influenced by factors such as rainfall, which promotes cover crop development, resulting in greater biomass accumulation. Differences were noted in the contribution of each cover crop species to the total dry matter phytomass at the end of the experiment for two or three species mixtures. Although CV and FR were sown at 25% of the total seed quantity in the three-species mixtures, their final contribution varied. In the BO + CV + FR and R + CV + FR treatments, CV accounted for 5.21–8.21% of the total dry matter phytomass in 2022, whereas FR dominated in 2023, contributing 57.33–75.59% (Table 1). These results corroborate those of Santos et al. (2024), who observed variations in the final species composition in the dry matter biomass. In the R + CV + FR treatment, CV and FR exhibited aggressive growth in 2023, completely suppressing the other species and leading to their absence in dry matter phytomass at the time of cover crop sampling. This may be linked to the rapid establishment of FR, which has strong adaptability to low-altitude environments and sandy-textured soils, enabling it to grow taller and dominate other cover crops (Bainard et al., 2020).

Table 1. Percentage composition of dry matter phytomass in cover crop treatments and total dry matter phytomass production at the end of the cycle for the different experimental years.

Treatment	BO (%)	R (%)	CV (%)	FR (%)	Dry phytomass (kg h^{-1})
2022 Season					
BO	100				4063.67^{aB}
R		100			3894.87^{aA}
CV			100		2999.99^{aB}
FR				100	4219.35^{aA}
BO+CV	68.33		31.67		3612.23^{aA}
BO+FR	40.08			59.22	4085.03^{aA}
BO+CV+FR	40.57		5.21	54.22	3834.31^{aA}
R+CV		69.41	30.59		4055.16^{aA}
R+FR		32.27		67.73	4112.61^{aA}
R+CV+FR		41.14	8.21	50.65	3491.60^{aB}
Mean for monoculture treatments (BO+R+FR+CV)					3794.47
Mean for cover crop mixtures					3865.16
Overall mean across all treatments					3836.88
2023 Season					
BO	100				6609.33^{aA}
R		100			3448.91^{bA}
CV			100		4731.38^{bA}
FR				100	3001.86^{bA}
BO+CV	29.58		70.42		4979.40^{bA}
BO+FR	25.75			75	3517.42^{bA}
BO+CV+FR	20.26		22.41	57.33	3995.87^{bA}
R+CV		18.67	81.33		4931.12^{bA}
R+FR		11.88		88.12	4485.90^{bA}
R+CV+FR		00.00	24.41	75.59	5835.38^{bA}
Mean for monoculture treatments (BO+R+FR+CV)					4447.87
Mean for cover crop mixtures					4624.18
Overall mean across all treatments					4553.66

BO = black oat; R = rye; CV = common vetch; FR = forage radish. *Means followed by the same lowercase letter in the column and uppercase letter between the years of evaluation do not differ by the Scott–Knott test at a 5% significance level.

In the 2022 season, there was no significant difference in dry matter phytomass production between the treatments (monoculture or mixtures). Nevertheless, in 2023, this variable was significantly higher in the BO monoculture compared to the other treatments since BO is a rustic forage species and adapted to varied climatic and soil conditions (Meira et al., 2019). BO dry matter phytomass production was 5336.49 kg ha^{-1}, averaged across both years, which is higher than the 4208.40 kg ha^{-1} reported by Ribeiro et al. (2017) for BO sown at 100 kg ha^{-1} in the Catarinense Plateau, Brazil. The values for R are similar to those recorded by Hanisch et al. (2020) (3794.00 kg ha^{-1}), with an average of 3671.89 kg ha^{-1} in the 2022 and 2023 trials. For CV, the average dry matter phytomass production was 3865.68 kg ha^{-1}, which exceeds the 3003.65 kg ha^{-1} reported by Ortiz et al. (2014). The average production of FR was 3610.60 kg ha^{-1} for both years, which is higher than the 3486.25 kg ha^{-1} reported by Ribeiro et al. (2017). In three consecutive growing seasons, Michelon et al. (2019) observed higher biomass accumulation when using cover crop mixtures, such as BO + FR + CV and BO + CV, compared to monoculture.

These findings corroborate our results, as dry matter phytomass production in mixtures exceeded the average values for the crops in monoculture. Although these biomass production values are similar, cover crop mixtures offer additional agronomic and economic advantages since they differ in their physiological characteristics, adaptation strategies (Yousefi et al., 2024), and root system architecture (Burr-Hersey et al., 2017). The use of cover crops reduces costs, preserves soil health, and enhances economic crop stability. Therefore, utilizing cover crops, whether in monoculture or mixtures, in rotation with commercial crops, increases efficiency and sustainability in Cerrado agricultural systems (Silva et al., 2021). In studies conducted in Santa Catarina, Brazil, over eight years, Souza et al. (2021) found that soil chemical properties and crop productivity were influenced by the use of cover crops over time in no-tillage system.

Higher biomass production promotes better soil coverage, protecting it from external environmental factors. In 2022, monoculture treatments (BO, R, CV, and FR) followed a linear soil coverage curve during the evaluation period, with coverage increasing until approximately 95 days after emergence (Figure 2). The best model fit was also linear for the BO + CV and BO + FR mixtures. In 2023, monoculture treatments (BO, R, CV, and FR) followed a quadratic function, with soil coverage peaking around 75 days after emergence and then declining (Figure 2). The cubic plant growth model was the best fit for cover crop mixtures BO + CV, BO + FR, BO + FR + CV, R + CV, R + FR, and R + FR + CV. This behavior may be attributed to the growth dynamics of the plant species in the mixtures. BO and FR exhibit rapid early development, covering the soil faster than the other species. However, the soil coverage temporarily decreased as BO grew and FR began branching; at this stage, R and CV exhibited secondary growth, contributing to a second peak in biomass production, which restored soil coverage. The extent of this secondary growth response varied across treatments depending on the rainfall pattern in 2023, during which there was a homogeneous distribution of rainfall that occurred throughout the growing season of fall/winter 2023, resulting in faster ground cover than 2022, which had high rainfall concentrations only at the beginning of the season.

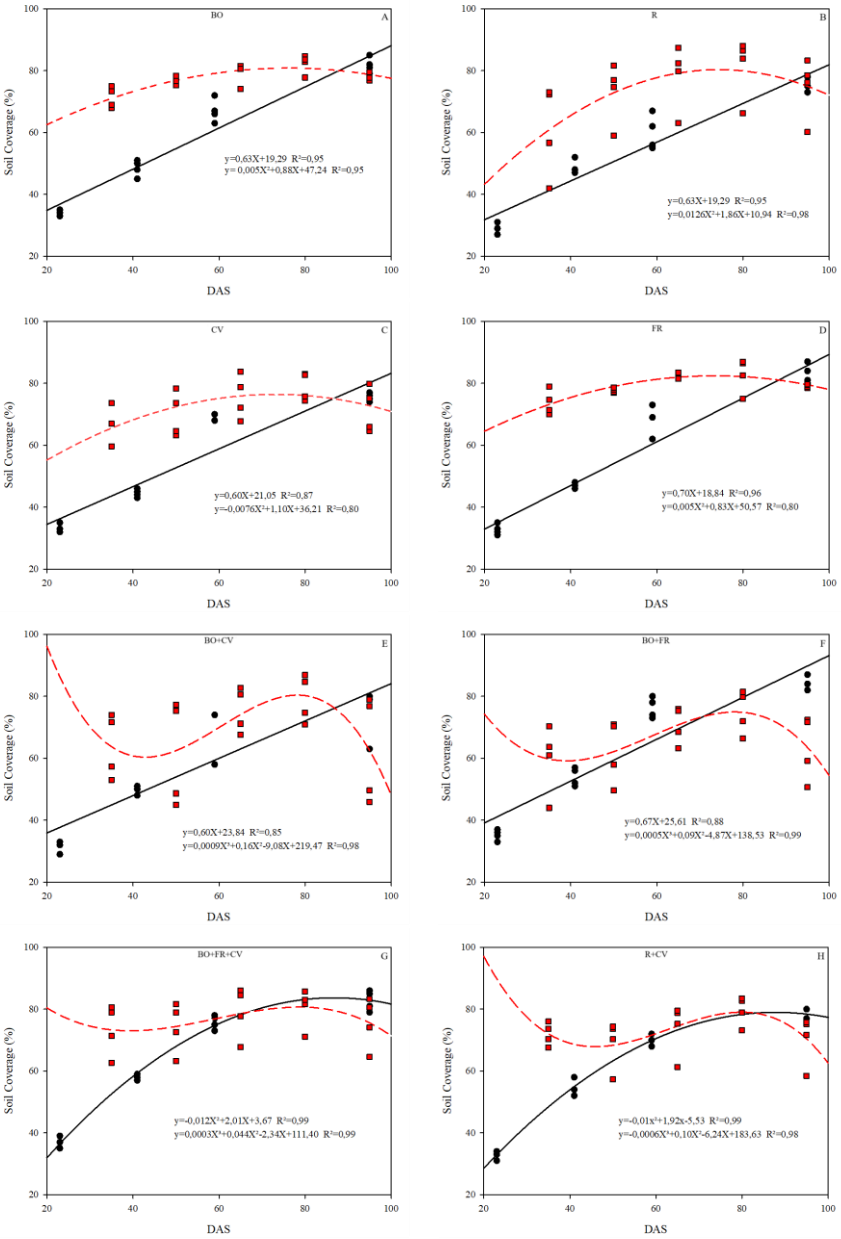

Figure 2. Soil coverage curves for different cover crops determined using the NDVI system with the GreenSeeker® device. Black oat (A); rye (B); common vetch (C); forage radish (D); black oat + common vetch (E); black oat + forage radish (F); black oat + forage radish + common vetch (G); rye + common vetch (H); rye + forage radish (I); rye + forage radish + common vetch (J). Continuous lines (-) represent 2022 data and dashed lines (--) represent 2023 data.

After measuring the dry matter phytomass, different decomposition behaviors were observed for the 2022 and 2023 decomposition periods (Figure 3). The dynamics of phytomass decomposition are related to the plant material composition, C/N ratio, mass production volume, crop management employed, fertility and pH of the soil, soil fauna activity, and climatic conditions (Alvarenga et al., 2001; Rosa et al., 2024; 2025).

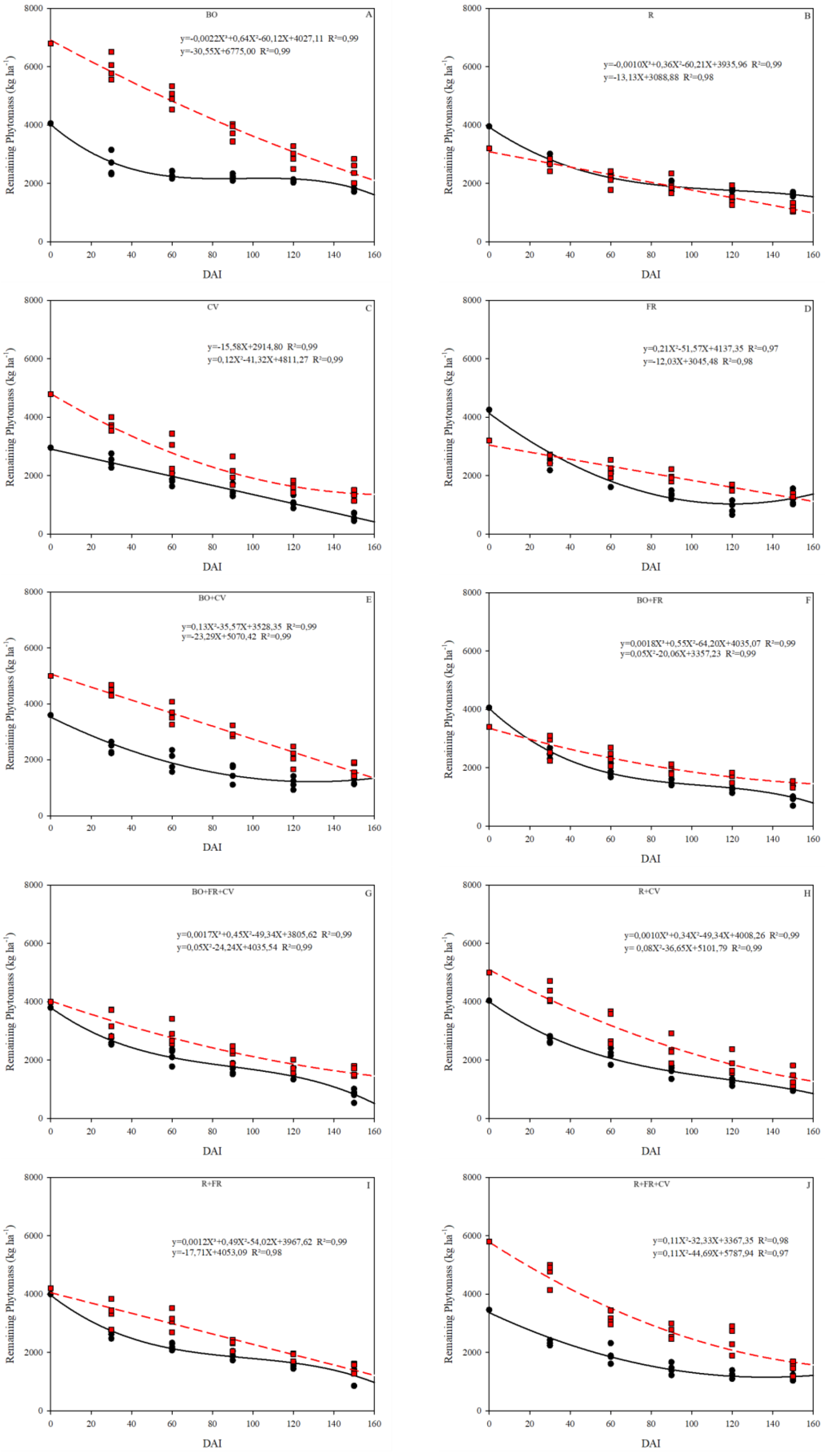

Figure 3. Decomposition curve of different cover crops, expressed as the remaining dry matter on the soil after different periods: black oat (A); rye (B); common vetch (C); forage radish (D); black oat + common vetch (E); black oat + forage radish (F); black oat + forage radish + common vetch (G); rye + common vetch (H); rye + forage radish (I); rye + forage radish + common vetch (J). Continuous lines (-) represent 2022, and dashed lines (--) represent 2023.

In 2022, the cubic function provided the best model fit for BO and R, demonstrating initial rapid decomposition of low-lignified tissues, followed by a decline in the decomposition rate over time as stalks continued to decompose. Common vetch, a legume with a high decomposition rate, showed continuous reductions in dry matter phytomass, corroborating the results of Doneda et al. (2012). The quadratic function best explained the decomposition pattern for FR, as shown in Figure 3. Santos et al. (2024) found that intercropping BO with CV led to a slower decomposition rate than CV grown alone, aligning with the results of this study. This is linked to the quality of the plant material, especially the C/N ratio (Cassol et al., 2023).

The decomposition curves in 2023 differed from those observed in 2022. For BO, R, and FR monocultures and BO + CV and R + FR mixtures, the linear functions best described the decomposition rates. For CV, BO + FR, BO + CV + FR, R + CV, and R + CV + FR, the quadratic function provided the best fit for the decomposition pattern over the evaluation period. The variation between the decomposition curves for 2022 and 2023 is linked to rainfall, as there was greater rainfall throughout the subsequent harvest in 2023, contributing to the differences in the decomposition rates.

On average, BO and R monocultures retained over 40% of their initial dry matter phytomass after 150 days of decomposition in both years, indicating slower degradation and greater residue persistence for soil protection, which was mainly related to their high C/N ratio. Conversely, due to its lower C/N ratio, CV exhibited the highest decomposition rate, with 74% of its initial biomass degraded, becoming the cover crop with the fastest decomposition and greatest increase in biological N fixation. Thus, the functional complementarity between the species used in the cover crop mixtures stands out. Although legumes (CV and FR) enable biological N fixation and improve canopy structure (Luo et al., 2024), grasses (BO and R) have a high leaf area index and vegetative vigor (Montaldo et al., 2023).

Conclusion

Among the evaluated species, forage radish exhibited the highest contribution to the total phytomass in all mixed treatments, maintaining dominance above 50%, even when sown at only 25% of the total seed proportion. This confirms the suitability of forage radish for intercropping in subtropical environments. Forage radish and black oat produced a higher dry matter phytomass. All cover crops, whether in monoculture or mixtures, provided adequate soil coverage by 50 days after sowing. Greater differences in soil coverage were observed between years rather than species. The autumn/winter of 2023, which experienced well-distributed rainfall, resulted in a faster soil coverage than 2022, which experienced heavy early season rainfall concentrations. After 150 days of decomposition, black oat and rye exhibited the lowest decomposition rates, retaining 41.18 and 38.86% of their initial biomass, respectively. Cover crop mixtures had intermediate decomposition rates, confirming their suitability as autumn/winter cover crops in subtropical environments, where they enhance nutrient cycling and extend soil protection.

Data availability

Not applicable.

Acknowledgements

This study was supported by the Coordination for the Improvement of Higher Education Personnel (CAPES), the National Council for Scientific and Technological Development (CNPq) and Research Support Foundation of the State of Rio Grande do Sul (FAPERGS).

References

Allan, E., Manning, P., Alt, F., Binkenstein, J., Blaser, S., Blüthgen, N., Böhm, S., Grassein, F., Hötzel, N., Klaus, V. H., Kleinebecker, T., Morris, E. K., Oelmann, Y., Prati, D., Renner, S. C., Rillig, M. C., Schaefer, M., Schloter, M., Schmitt, B., ... Fischer, M. (2015). Land use intensification alters ecosystem multifunctionality via loss of biodiversity and changes to functional composition. *Ecology Letters*, *18*(8), 834-843. https://doi.org/10.1111/ele.12469

Almeida, D. O., Bayer, C., & Almeida, H. C. (2016). Fauna e atributos microbiológicos de um Argissolo sob sistemas de cobertura no Sul do Brasil. *Pesquisa Agropecuária Brasileira*, *51*(9), 1140-1147. https://doi.org/10.1590/S0100-204X2016000900013

Asadi, S., Bannayan, M., Jahan, M., & Farid Hosseini, A. (2019). Using the red-near infrared spectral to estimate ground cover based on vegetative indices. *International Journal of Remote Sensing*, *40*(18), 7153-7168. https://doi.org/10.1080/01431161.2019.1601282

Alvarenga, R. C., Cabezas, W. A. L., Cruz, J. C., & Santana, D. P. (2001). Plantas de cobertura de solo para sistema plantio direto. *Informe Agropecuário*, *22*(208), 25-36.

Alvares, C. A., Stape, J. L., Sentelhas, P. C., Moraes Gonçalves, J. L., & Sparovek, G. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, *22*(6), 711-728. https://doi.org/10.1127/0941-2948/2013/0507

Bainard, J. D., Serajchi, M., Bainard, L. D., Schellenberg, M. P. & Lamb, E. G. (2020). Impact of diverse annual forage mixtures on weed control in a semiarid environment. *Frontiers in Sustainable Food Systems*, *4*(92), 1-9. https://doi.org/10.3389/fsufs.2020.00092

Basche, A. D., & DeLonge, M. S. (2019). Comparing infiltration rates in soils managed with conventional and alternative farming methods: A meta-analysis. *PLoS ONE*, *14*(9), 1-22. https://doi.org/10.1371/journal.pone.0215702

Borgogno-Mondino, E., Lessio, A., Tarricone, L., Novello, V., & Palma, L. (2018). A comparison between multispectral aerial and satellite imagery in precision viticulture. *Precision Agriculture*, *19*(9), 195-217. https://doi.org/10.1007/s11119-017-9510-0

Burr-Hersey, J. E., Mooney, S. J., Bengough, A. G., Mairhofer, S., & Ritz, K. (2017). Developmental morphology of cover crop species exhibit contrasting behaviour to changes in soil bulk density, revealed by X-ray computed tomography. *PLoS ONE*, *12*(7), 1-18. https://doi.org/10.1371/journal.pone.0181872

Cargnelutti Filho, A., Silveira, D. L., Loregian, M. V., Osmari, L. F., & Ortiz, V. M. (2022). Dimensionamentos experimentais e precisão em ensaios com consórcio de aveia preta, ervilhaca e nabo forrageiro. *Revista Brasileira de Ciências Agrárias*, *17*(2), 1-8. https://doi.org/10.5039/agraria.v17i2a129

Cassol, C., Conceição, P. C., Amadori, C., Haskel, M. K., Freitas, L. A. de, & Tomazoni, A. R. (2023). Índice de qualidade da biomassa residual: uma ferramenta para a agricultura de conservação. *Revista Brasileira de Ciência do Solo*, *47*, 1-18. https://doi.org/10.36783/18069657rbcs20220150

Companhia Nacional de Abastecimento. (2024). *Monitoring of the Brazilian grain harvest - 2023/24 harvest*. CONAB.

Doneda, A., Aita, C., Giacomini, S. J., Miola, E. C. C., Giacomini, D. A., Schirmann, J., & Gonzatto, R. (2012). Fitomassa e decomposição de resíduos de plantas de cobertura puras e consorciadas. *Revista Brasileira de Ciência do Solo*, *36*(6), 1714-1723. https://doi.org/10.1590/S0100-06832012000600005

Fontaneli, R. S., Santos, H. P., Fontaneli, R., Hentz, P., & Lehmen, R. I. (2012). Forrageiras para integração lavoura-pecuária na região sul-brasileira. *Synergismus Scyentifica*, *6*(2), 1-29.

Hanisch, A. L., Balbinot Junior, A. A., Fonseca, J. A., & Vogt, G. A. (2020). Consórcios de gramíneas anuais de inverno com e sem fertilização. *Agropecuária Catarinense*, *25*(3), 51-53. https://doi.org/10.52945/rac.v25i3.663

Luo, F., Mi, W., & Liu, W. (2024). Legume–grass mixtures improve biological nitrogen fixation and nitrogen transfer by promoting nodulation and altering root conformation in different ecological regions of the Qinghai–Tibet Plateau. *Frontiers in Plant Science*, *15*, 1-16. https://doi.org/10.3389/fpls.2024.1375166

Meira, D., Meier, C., Olivoto, T., Nardino, M., Rigatti, A., Klein, L. A., Caron, B. O., Marchioro, V. S., & Souza, V. Q. (2019). Phenotypic variance of black oat growing in crop seasons reveals genetic effects predominance. *Anais da Academia Brasileira de Ciências*, *91*(3), 1-9. https://doi.org/10.1590/0001-3765201920180036

Michelon, C. J., Junges, E., Casali, C. A., Pellegrini, J. B. R., Neto, L. R., Oliveira, Z. D., & Oliveira, M. D. (2019). Soil attributes and yield of corn cultivated in succession to winter cover crops. *Revista Ciências Agroveterinárias*, *18*(2), 230-239. https://doi.org/10.5965/223811711812019230

Montaldo, N., Gaspa, A., & Corona, R. (2023). Assimilation of NDVI data in a land surface – Vegetation model for leaf area index predictions in a tree-grass ecosystem. *International Journal of Digital Earth*, *16*(1), 3810-3837. https://doi.org/10.1080/17538947.2023.2259226

Ortiz, S., Martin, T. N., Brum, M. S., Nunes, N. V., Stecca, J. D. L., & Ludwig, R. L. (2014). Densidade de semeadura de duas espécies de ervilhaca sobre caracteres agronômicos e composição bromatológica. *Ciência Rural*, *45*(2), 245-251. https://doi.org/10.1590/0103-8478cr20140291

Pessotto, P. P., Silva, V. R., Ortigara, C., Koppe, E., Strojaki, T., & Santi, A. L. (2016). Influência de diferentes plantas de cobertura nas propriedades físicas de um latossolo vermelho. *Agrarian*, *9*(34), 348-356.

Pittman, K. B., Barney, J. N., & Flessner, M. L. (2020). Cover crop residue components and their effect on summer annual weed suppression in corn and soybean. *Weed Science*, *68*(3), 301-310. https://doi.org/10.1017/wsc.2020.16

R Core Team. (2024). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing.

Ribeiro, R. H., Besen, M. R., Figueroa, L. V., Bogo, T., Brancaleoni, E., Ronsani, S. C., Guginski-Piva, C. A., & Piva, J. T. (2017). Produção de fitomassa de diferentes plantas de cobertura de inverno com aplicação de nitrogênio. *Varia Scientia Agrárias*, *5*(2), 41-53.

Rosa, D. M., Nóbrega, L. H. P., Mauli, M. M., Lima, G. P., & Pacheco, F. P. (2017). Substâncias húmicas do solo cultivado com plantas de cobertura em rotação com milho e soja1. *Revista Ciência Agronômica*, *48*(2), 221–230. https://doi.org/10.5935/1806-6690.20170026

Rosa, G. B., Follmann, D. N., Bolzan, F. T., Eggers, H., Lúcio, A. D. C., Jacques, R. J. S., Portela, V. O., Marchioro, V. S., Klein, L. A., & Maldaner, I. C. (2024). Canonical correlations of maize yield components with biological and chemical soil indicators in a subtropical climate. *Australian Journal of Crop Science*, *18*(11), 715-722. https://doi.org/10.21475/ajcs.24.18.11.p97

Rosa, G. B., Follmann, D. N., Lúcio, A. D., Jacques, R. J. S., Portela, V. O., & Marchioro, V. S. (2025). Evaluation of soil fauna diversity in maize crops using Shannon, Margalef, and Pielou indices. *Acta Scientiarum. Agronomy*, *47*(1), 1-11. https://doi.org/10.4025/actasciagron.v47i1.69432

Ruis, S. J., Blanco-Canqui, H., Creech, C. F., Koehler-Cole, K., Elmore, R. W., & Francis, C. A. (2019). Cover crop biomass production in temperate agroecozones. *Agronomy Journal*, *111*(4), 1535-1551. https://doi.org/10.2134/agronj2018.08.0535

Santos, H. G., Jacomine, P. K. T., Anjos, L. H. C., Oliveira, V. A., Lumbreras, J. F., Coelho, M. R., Almeida, J. A., Araujo Filho, J. C., Oliveira, J. B., & Cunha, T. J. F. (2018). *Sistema brasileiro de classificação de solos* (5. ed.). Embrapa Solos.

Santos, E. D., Follmann, D. N., Schlösser, O. D., Pereira, A. C., Lucio, A. D. C., & Moresco, E. A. (2024). Winter cover crops grown in low altitude condition. *Semina: Ciências Agrárias*, *45*(4), 1185-1200. https://doi.org/10.5433/1679-0359.2024v45n4p1185

Silva, M. A., Nascente, A. S., Frasca, L. L. M., Rezende, C. C., Ferreira, E. A. S., Filippi, M. C. C., Lanna, A. C., Ferreira, E. P. B. & Lacerda, M. C. (2021). Isolated and mixed cover crops to improve soil quality and commercial crops in the Cerrado. *Research, Society and Development*, *10*(12), 1–11. https://doi.org/10.33448/rsd-v10i12.20008

Singh, G., Kaur, G., Williard, K. W. J., & Schoonover, J. E. (2021). Cover crops and tillage effects on carbon–nitrogen pools: A lysimeter study. *Vadose Zone Journal*, *20*(2), 1-20. https://doi.org/10.1002/vzj2.20110

Souza, M., Müller Junior, V., Kurtz, C., Ventura, B. S., Lourenzi, C. R., Lazzari, C. J. R., Ferreira, G. W., Brunetto, G., Loss, A., & Comin, J. J. (2021). Soil chemical properties and yield of onion crops grown for eight years under no-tillage system with cover crops. *Soil and Tillage Research*, *208*, 104897. https://doi.org/10.1016/j.still.2020.104897

Wayman, S., Kucek, L. K., Mirsky, S. B., Ackroyd, V., Cordeau, S., & Ryan, M. R. (2017). Organic and conventional farmers differ in their perspectives on cover crop use and breeding. *Renewable Agriculture and Food Systems*, *32*(4), 376-385. https://doi.org/10.1017/S1742170516000338

Yousefi, M., Dray, A., & Ghazoul, J. (2024). Assessing the effectiveness of cover crops on ecosystem services: a review of the benefits, challenges, and trade-offs. *International Journal of Agricultural Sustainability*, *22*(1), 1-15. https://doi.org/10.3929/ethz-b-000669605

Ziech, A. R. D., Conceição, P. C., Luchese, A. V., Balin, N. M., Candiotto, G., & Garmus, T. G. (2015). Soil protection by winter-cycle cover crops in South Brazil. *Pesquisa Agropecuaria Brasileira*, *50*(5), 374-382. https://doi.org/10.1590/S1678-3921.pab2015.v50.20934

Associate Editor in charge:
Alessandro Lucca Braccini
ORCID: https://orcid.org/0000-0002-6915-4804
Carlos Alberto Scapim
ORCID: https://orcid.org/0000-0002-7047-9606