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Winter cover crops grown in low altitude condition

Plantas de cobertura hibernais cultivadas em condição de baixa altitude

Emilso Damm dos Santos[1]*; Diego Nicolau Follmann[2]; Onássis Deivis Schlösser[1]; Anderson Crestani Pereira[1]; Alessandro Dal'Col Lucio[2]; Estéfano Antonio Moresco[3]

Highlights

Soil covering using the NDVI system.

FT in single cultivation has high potential for soil coverage in early periods.

AP and AB showed greater maintenance of dry phytomass in soil cover.

Abstract

The purpose of the study was to evaluate dry matter phytomass production, percentage of soil cover, and dry matter phytomass decomposition curve of cover crops in single and mix cultivation, in a low-altitude subtropical environment. The study was conducted in Santa Maria - RS, in agricultural years 2019/2020 and 2021/2022. The experimental design used was randomized blocks, with ten treatments and four replications. The experiments were conducted with four winter cover crops: White oat (WO), black oat (BO), forage turnip (FT), and common vetch (CV), in single cultivation and as a mix of cover plants. For the total production of dry matter phytomass, the FT and BO+CV+FT treatments stand out which present the highest averages between the experimental years, with values 4365.32 and 4109.87 kg ha^{-1}. FT in single cultivation has a high potential for soil coverage in periods of 45 DAS, and the common vetch crop showed greater soil coverage in the late period, with 84% coverage at 90 days after sowing. The BO and WO treatments showed greater maintenance of dry phytomass in soil cover at the end of the 150-day period, presenting values greater than 40% of the initial volume of dry phytomass present in the production system. Recommending the exclusive cultivation of the species that meets the rural producer's objective.

Key words: NDVI. *Avena sativa* L.. *Avena strigosa* Schreb.. *Raphanus sativus* L.. *Vicia sativa* L.

[1] Students of the Doctoral Course of the Postgraduate Program in Agronomy, Universidade Federal de Santa Maria, UFSM, Santa Maria, RS, Brazil. E-mail: emilsoeds@gmail.com; onassis322013@gmail.com; acrestanipereira@gmail.com

[2] Profs. Drs., Department of Phytotechnics, UFSM, Santa Maria, RS, Brazil. E-mail: diego.follmann@ufsm.br; adlucio@ufsm.br

[3] Student of the Master's Course of the Postgraduate Program in Agronomy, UFSM, Santa Maria, RS, Brazil. E-mail: moresco1998@hotmail.com

* Author for correspondence

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Resumo

O objetivo do estudo foi avaliar a produção de fitomassa da matéria seca, a porcentagem de cobertura do solo e a curva de decomposição da fitomassa da matéria seca de plantas de cobertura em cultivo solteiro e misto, em ambiente subtropical de baixa altitude. O estudo foi realizado em Santa Maria – RS, nos anos agrícolas 2019/2020 e 2021/2022. O delineamento experimental utilizado foi blocos casualizados, com dez tratamentos e quatro repetições. Os experimentos foram conduzidos com quatro culturas de cobertura de inverno: aveia branca (AB), aveia preta (AP), nabo forrageiro (NB) e ervilhaca comum (EC), em cultivo único e em mistura de plantas de cobertura. Para a produção total de fitomassa de matéria seca destacam-se os tratamentos NB e AP+EC+NB, que apresentam as maiores médias entre os anos experimentais, com valores 4365.32 e 4109.87 kg ha-1. O NB em cultivo solteiro apresenta alto potencial de cobertura do solo em períodos de 45 DAS, e a cultura da ervilhaca apresentou maior cobertura do solo no período tardio, com 84% de cobertura aos 90 dias após a semeadura. Os tratamentos AP e AB apresentaram maior manutenção da fitomassa seca na cobertura do solo ao final do período de 150 dias, apresentando valores superiores a 40% do volume inicial de fitomassa seca presente no sistema de produção. Recomenda-se o cultivo estreme da espécie que satisfazer o objetivo do produtor rural visa alcançar.
Palavras-chave: NDVI. *Avena sativa* L.. *Avena strigosa* Schreb.. *Raphanus sativus* L.. *Vicia sativa* L.

Introduction

Species used as cover plants actively contribute to covering the soil surface, bringing benefits such as reducing water loss through evaporation and reducing soil erosion (Donagemma et al., 2016). Water plays a crucial role in the development of crops, with its deficit causing a reduction in grain yield (Sousa et al., 2015). A methodology used to determine land cover is the NDVI system (normalized difference vegetation index) (Borgogno-Mondino et al., 2018). This methodology allows for application in precision agriculture, comprising the overall assessment of the crop status (Barbanti et al., 2018).

This highlights the importance of knowing the development of cover crops, helping to adjust management for greater efficiency in the use of resources in the growing environment. Due to the occurrence of climatic phenomena such as El Niño and La Niña, which have an influence on the water regime in southern Brazil: When we have El Niño conditions, greater volumes of precipitation occur, and when we have La Niña, lower volumes of rainfall during the summer period occur (Junges et al., 2019). In addition to the occurrence of ENSO phenomena, other factors such as the reduction in altitude influence the yield potential of summer crops.

According to Körner (2007), there are some atmospheric changes associated with low altitude when compared to high altitude environments, such as an increase in air temperature, changes in ambient humidity, and lower solar radiation under clear skies. To this end, the lower altitude environment provides nights with high mean temperatures and greater energy expenditure by the plant through the respiration process (Taiz et al., 2017). Meanwhile, net photosynthesis shows a sharp increase at low nighttime temperatures (Bergamaschi & Matzenauer, 2014), factors that negatively affect the final productivity of summer crops and that are not subject to change in the cultivation environment. Therefore, management strategies must be adopted to provide better cultivation conditions, in order to enable gains in grain yield. One strategy is the appropriate use of cover crops.

Improvements in the growing environment can be enhanced when using a consortium, or mix of cover crops, especially when combining species with contrasting characteristics (Ziech et al., 2015). Through the consortium of cover crops, we obtain efficiency in soil coverage and satisfactory production of phytomass (Ribeiro et al., 2017). It is known that cover crops are important before summer crops, and there are studies in the literature conducted in higher altitude environments in southern Brazil.

However, studies on low-altitude subtropical environment with cover crops and mixed cover crops that precede summer crops is limited. Furthermore, in many cases, these studies do not explore the development and degradation of cover crop dry phytomass. Therefore, the purpose of this study was to evaluate dry matter phytomass production, percentage of soil cover, and dry matter phytomass decomposition curve of cover crops in single and mixed cultivation of cover crops in a low-altitude subtropical environment.

Materials and Methods

The experiment was conducted in an experimental area in Santa Maria, located in the Central Depression physiographic region, in the state of Rio Grande do Sul, Brazil (29º 43' 28" S, 53º 43' 41" W, altitude 95 m). The climate is characterized as humid subtropical (Cfa), with no defined dry season and with a mean rainfall of 1,616 mm per year (Alvares et al., 2013). The site characteristic soil is classified as sandy Dystrophic Red Argisol (Santos et al., 2018), with low fertility (Table 1).

Table 1
Soil fertility indicators for the experimental area in the years 2019/20 and 2021/22, during the period during which the cover crop experiments were conducted. Santa Maria, RS, 2023

Year	Depth (cm)	pH	Ca	Mg	Al	T	Saturation (%)		SMP	OM	Clay	P	K
		water							index			Mehlich	
		(1:1)	----- (cmolc dm^{-3}) -----				Al	Base		(%)	(%)	](mg dm^{-3})	
2019/20	0 - 20	4.4	2.3	1.2	2.4	6.1	39.3	13.1	4.5	1.7	30	3.1	40
2021/22	0 - 20	4.6	2.7	1.5	2.2	6.5	33.5	33	5.4	1.9	31	3.8	52

T = Cation exchange capacity; SMP = Index used for liming recommendations in the Rio Grande do Sul and Santa Catarina states; OM = organic matter.

The study was conducted in two agricultural years, in the 2019/20 and 2021/22 harvests, with sowing of cover crops on June 5th and April 12th, respectively. The experimental design used was randomized complete blocks, with four replications. The experimental plots were 1.8 m wide and 5.0 m long, containing a 9.0 m² useful area, with a spacing of 3 meters between blocks, constituting the borders of the plots.

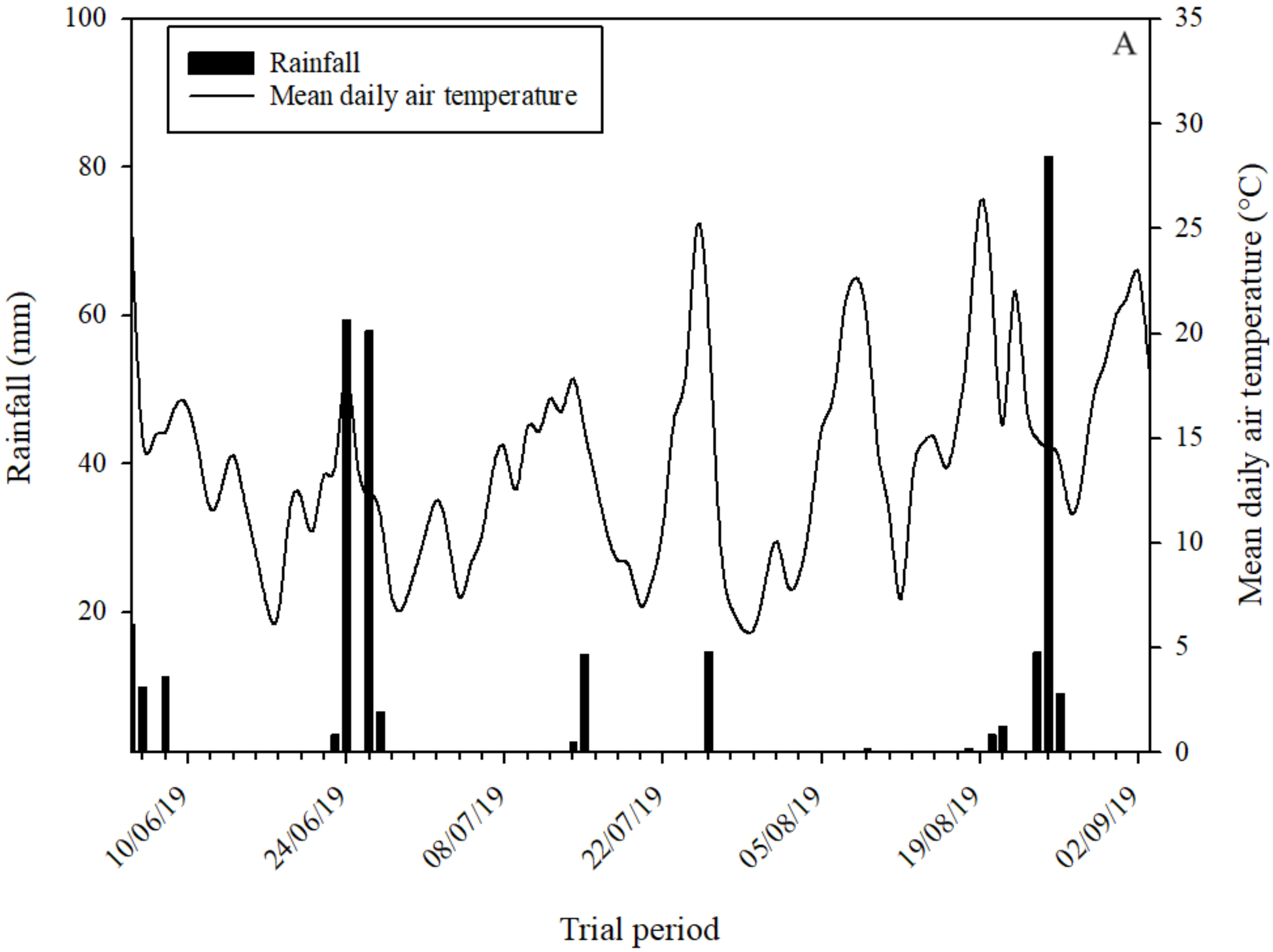
The experiment with the use of cover crops was organized with four species of cover crops, these species being the main winter cover plants in the cultivation system characteristic of the region, in single cultivation and in consortia (mix of cover crops), totaling 10 treatments. In the single cultivation, treatments were: T1 = Black Oats (BO), T2 = White Oats (WO), T3 = Common Vetch (CV), and T4 = Forage Turnip (FT). In the mix of cover crops with %D (adjusted density percentage, as a reference to the mixed cultivation), treatments were: T5 = Black Oats (50%D) + Common Vetch (50%D), T6 = Black Oats (50%D) + Forage Turnip (50%D), T7 = Black Oats (50%D) + Forage Turnip (25%D) + Common Vetch (25%D), T8 = White Oats (50%D) + Common Vetch (50%D), T9 = White Oats (50%D) + Forage Turnip (50%D), T10 = White Oats (50%D) + Forage Turnip (25%D) + Common Vetch (25%D). Where a density of 50%D was used for oats in all treatments in the form of a mix of cover crops, aiming to increase their longevity in the soil cover after management and desiccation of the mix.

The sowing density used for the cover crops was: Black oats = 80 kg ha^{-1}, White oats = 80 kg ha^{-1}, Common vetch = 50 kg ha^{-1} (Fontaneli et al., 2012), Forage turnip = 15 kg ha^{-1} (Cargnelutti et al., 2022). For the mixed cover crop treatments, the values of the seeds from each species to be used follow each species participation percentage, taking as a reference the crop density itself.

The species presented different stages of development when evaluating the dry mass production of cover crops. When phytomass samples were taken from 2 m² of each plot to measure the total dry matter phytomass of the plot and of the individual components of the treatments, either in cultivation alone or in a mix of cover crops. Where in 2019/20 oats were in the initial flowering stage, common vetch without apparent flowering, and forage turnip in the final flowering stage. And for the year 2021/22, oats in the final flowering stage, common vetch in the early flowering stage, and forage turnip in the silique formation stage. And this sampling was carried out 88 days after sowing in the 2019/20 harvest and 110 days for 2021/22. The assessment of soil cover was carried out using the NDVI system with the Green Seeker® equipment, which measures the vegetation index by standardized difference. The greater the soil coverage by plants, the higher the NDVI value, which ranges between 0.00 (lowest value) and 1 (highest value). Therefore, this evaluation was carried out at 4 moments during the development of the cover crops, at 45, 60, 75 and 90 days after sowing.

To evaluate the decomposition rate, the decomposition speed of residues from cover crops was evaluated using litter bags (Ziech et al., 2015), made of voile fabric, 1 mm-mesh, measuring 25 x 20 cm, totaling 0.05 m². In the litter bags, greenhouse-dried plant material was added in an amount proportional to the phytomass of dry matter produced by the cover crops in the plots. They were distributed in 4 replications, and 6 collections were conducted at time intervals of 0, 30, 60, 90, 120, and 150 days of exposure to the decomposition of plant material in contact with the soil.

During the experimental period, data on climatic variables of precipitation and average daily temperature were collected from the automatic meteorological station belonging to the national meteorology institute (INMET), located 300 meters from the experimental area (Figure 1).



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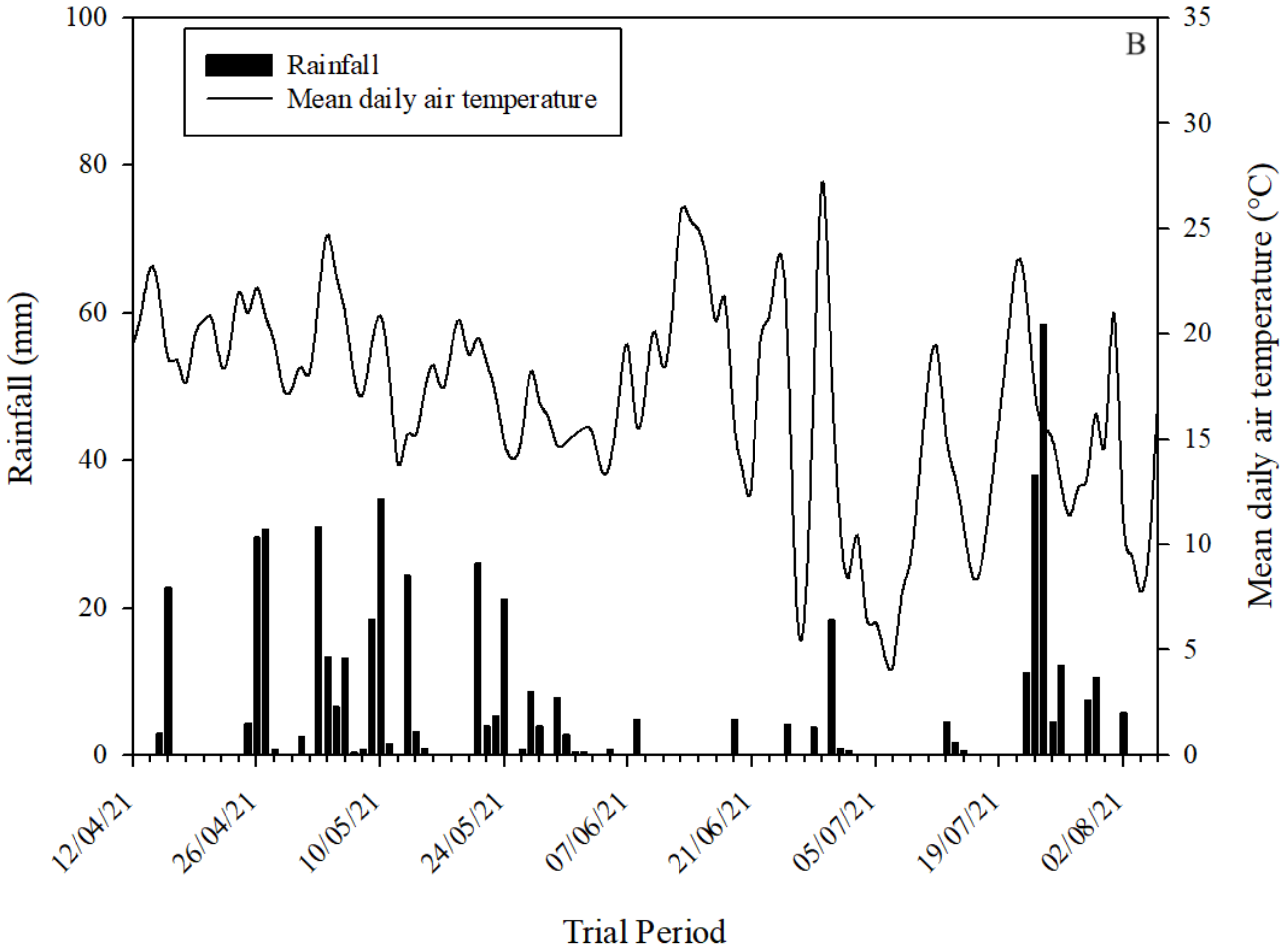

Figure 1. Rainfall volumes and mean daily air temperature during the development period of cover crop treatments in the 2019/20 (A) and 2021/22 (B) harvest, according to data obtained at the INMET meteorological station, installed in Santa Maria, RS, 2023.

The different variables collected were subjected to analysis of variance (ANOVA) to determine the existence of differences between treatments, carrying out a joint analysis of data from the different years. Subsequently, the dry phytomass data were subjected to the Scott-Knott mean clustering test at 5% error probability and the soil cover and dry phytomass decomposition data to regression analysis at 5% error probability, using R software version 4.2.1 (R Core Team, 2022). Graphic production was carried out using Sigma Plot software.

Results and Discussion

Mean daily temperatures for the period and rainfall volumes were verified (Figure 1). During the experimental period of cover crops in the 2019/20 harvest, rainfall occurred with a volume of 323.2 mm, while in the 2021/22 harvest the volume was 517.6 mm. The mean daily rainfall was 3.55 mm in the 2019/20 harvest and 4.42 mm in the 2021/22 harvest.

Although the occurrence of these rainfall volumes was not uniform, periods of water deficit were not observed during the development of cover crop species, due to the lower water demand in the autumn/winter period.

Likewise, one of the climatic indicators that has the greatest potential to change the grain yield of summer crops is rainfall (Sousa et al., 2015). To minimize the effects of water deficits, an alternative is to use cover crops (Dechen et al., 2015). Thus, the present study demonstrates the existence of a statistical difference between cover crop treatments (Table 2), allowing characteristics such as the composition of this plant material and the volume of dry biomass production (Table 3) to present different decomposition dynamics.

Table 2
Joint variance analysis for total dry phytomass in the 2019/20 and 2021/22 harvests, for the treatments of BO (Black oats), WO (White oats), CV (Common vetch), FT (Forage turnip), and the different mixes of cover crops. Santa Maria, RS, 2023

FV	DF	SS	MS	FC	PR>FC
Treatment	9	29867571.98	3318619.10	7.125	0.0000
Block	1	1160184.77	386728.25	0.830	0.4827
Year	3	60802226.37	60802226.37	130.544	0.0000
Treatment X Year	57	36189789.99	4021087.77	8.633	0.0000
Error		26548423.67	465761.81		
CV (%)		20.00			

Table 3
Percentage composition of dry phytomass of cover crop treatments and total dry phytomass produced in the years 2019 and 2021, for the treatments of BO (Black oats), WO (White oats), CV (Common vetch), FT (Forage turnip), and the different mixes of cover crops. Santa Maria, RS, 2023

TREATMENT	White oats (WO)(%RT)	Black oats (BO) (%RT)	Common vetch (CV)(%RT)	Forage turnip (FT)(%RT)	Dry phytomass (kg ha-¹)
		HARVEST 2019/20			
BO		100			3017.09 a*
WO	100				1290.44 b
CV			100		347.12 b
FT				100	3474.79 a
BO+CV		97.76	2.24		2523.27 a
BO+FT		10.56		89.44	3571.68 a
BO+CV+FT		26.99	0.13	72.88	3965.05 a
WO+CV	94.25		5.75		1098.68 b
WO+FT	5.20			94.80	2815.48 a
WO+CV+FT	8.31		0.28	91.42	3304.94 a
		HARVEST 2021/22			
BO		100			4564.30 a
WO	100				4813.35 a
CV			100		4173.48 a
FT				100	5255.85 a
BO+CV		85.33	14.66		3791.71 b
BO+FT		29.66		70.33	4416.39 a
BO+CV+FT		32.72	20.62	46.65	4254.69 a
WO+CV	58.25		41.74		4709.10 a
WO+FT	15.34			84.65	3469.65 b
WO+CV+FT	15.72		5.56	78.70	3395.84 b

*means followed by the same letter do not differ according to the Scott-Knott test, at 5% significance (p>0.05). * %RT = percentage relative to the treatment total dry matter phytomass.

Thus, for different species such as forage turnip, present in the BO+CV+FT and WO+CV+FT treatments, with 25% of the seeds implanted in a mix composed of 3 species and 50% in a mix with 2 plant species, treatments BO+FT and WO+FT. It presents at least 46.65% participation in the dry phytomass of the BO+CV+FT treatment, in the 2021/22 harvest, and in the others, it presents values above 70%. Mainly due to its rapid initial growth, in order to stand out from other species cultivated together, another factor that may be associated is its tolerance to soils with lower pH (Lima et al., 2014), characteristic to the central region of RS, in addition to its rusticity and adaptability of cultivation in less fertile soils (Lima et al., 2014). Demonstrating its capacity for rapid establishment and competitive aggressiveness, this cover crop has interesting characteristics for soil protection and competition with weeds.

Common vetch behaves in the opposite way to forage turnip. However, the percentage values of installed seeds are identical to that of forage turnip. It presents maximum values of 20% participation in dry matter phytomass, except for WO+CV, in the 2021/22 harvest, which presented a value greater than 41% participation. However, these higher values were found in the second year of experiments, with a small improvement in the fertility of the experimental area. Thus, common vetch develops well in soils that are already cultivated and without acidity problems (Lima et al., 2014).

For dry matter phytomass production, the highest mean values in the 2019/20 harvest were obtained by the BO+CV+FT treatment, with a 3,965.05 kg ha-1 biomass, although there was no difference in relation to the other treatments. This value was exceeded in the 2021/22 harvest by treatments BO, WO, CV, FT, BO+FT, BO+CV+FT, and WO+CV. The FT treatment stands out, with 5,255.85 kg ha-1 of dry matter phytomass, a result similar to that observed by Krenchinski et al. (2018), who obtained in an average of three years of experiments more than 5,500.00 kg ha-1 of dry phytomass of forage turnip in their study. The other treatments, which presented lower average values, were also statistically lower than those previously mentioned. As a highlight, the low altitude subtropical environment can produce dry matter phytomass close to or higher than the values found in other studies in higher altitude environments in Brazil, such as the values obtained for black oats, of 4,700.00 kg ha-1 (Ziech et al., 2015), and for common vetch, 3,000.00 kg ha-1 (Ortiz et al., 2015), as observed in the 2021/22 harvest. In relation to the experimental years, the 2021/22 harvest presented a higher mean than the previous year, with a difference of 1,743.59 kg between the years.

These different volumes of produced dry phytomass, as well as the developmental biology of each cover plant species, attribute different soil cover conditions (Ziech et al., 2015; Mottin et al., 2018) (Figure 2) during their vegetative period. Where it was observed that in the vast majority, the treatments fit a significant quadratic regression model. The exception was the FT treatment, which was fitted to a linear model. It was also observed that, except for the BO+FT treatment, which presented a 0.77 coefficient of determination (R^2), the other treatments presented R^2 greater than 0.94.

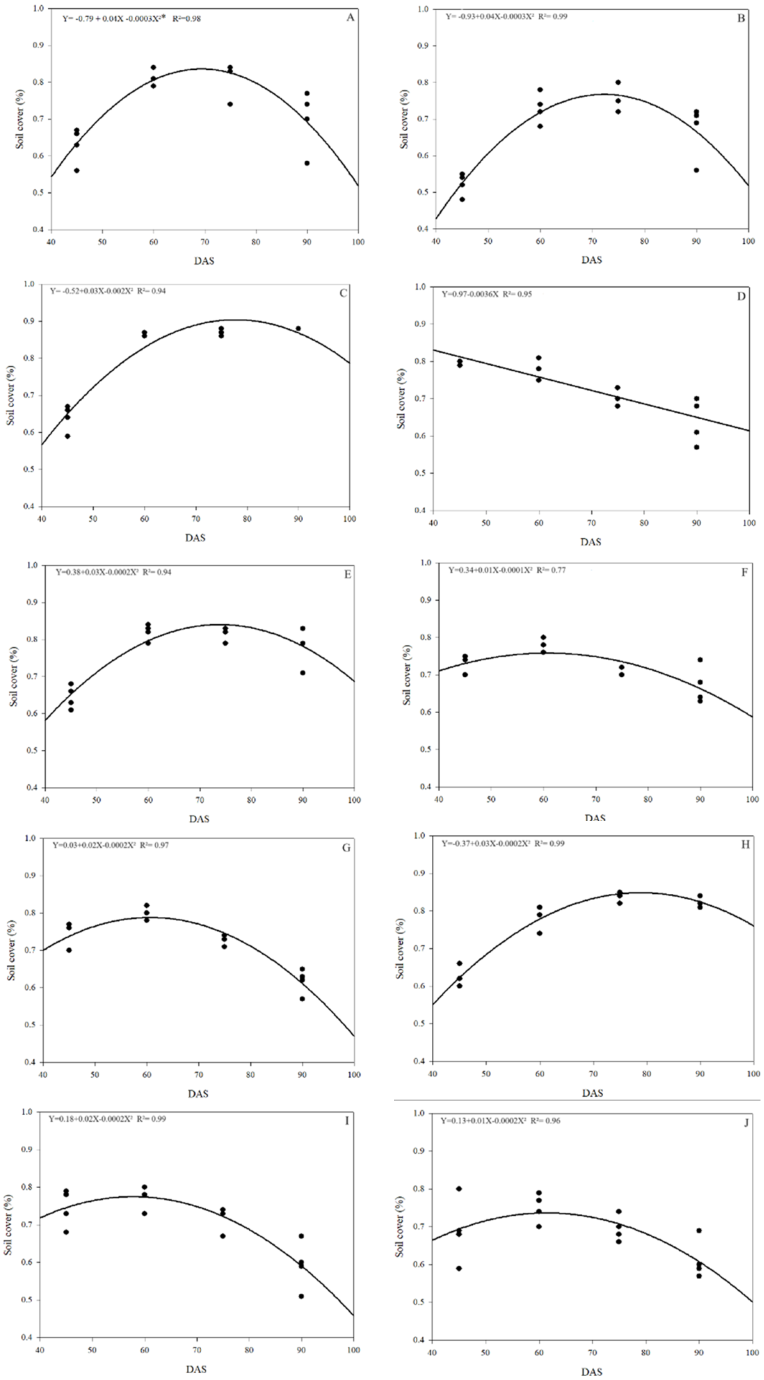

Figure 2. Soil cover curve, during the vegetative development (45 to 90 days after sowing) of crops Black oats (2A), White oats (2B), Common vetch (2C), Forage turnip (2D), in single and mixed cultivation of cover crops Black oats + Common vetch (2E), Black oats + Forage turnip (2F), Black oats + Common vetch + Forage turnip (2G), White oats + Common vetch (2H), White oats + Forage turnip (2I), and White oats + Common vetch + Forage turnip (2J), Santa Maria, RS, 2023. *All equations plotted in the graphs are significant at a 5% probability of error. For the y-axis (soil cover), the value scale is between 0 and 1, where 0 represents completely bare soil (0% soil coverage), and 1 corresponds to completely covered soil (100% soil coverage). from soil).

We observe that the FT treatment (Figure 2D) presents the highest level of soil coverage in the evaluation carried out at 45 DAS (days after sowing), with indices above 0.79, which are equivalent to 79% of soil coverage, showing a reduction of these indices in subsequent evaluations. Likewise, it is presented by Krenchinski et al. (2018) soil cover rates of 82% at 30 days after emergence, justifying this result due to its aggressive growth biology in the initial period of installation of the cover plant species (Krenchinski et al., 2018). However, when there is the presence of the forage turnip component in the cover crop mix (Figure 2F, 2G, 2I, and 2J) there was a decrease in soil coverage in all treatments in which forage turnip is present, from the 70 DAS, where the forage turnip showed stem growth and a reduction in the leaf proportion in the plant composition.

When evaluating BO (Figure 2A) and WO (Figure 2B) treatments in single cultivation, an increase in soil cover rates was obtained after 70 DAS, presenting values greater than 0.8 (80%). In comparison, Wolschick et al. (2016) found in their work that black oats, 60 days after emergence, showed 54% soil coverage, rates lower than those in the present study. In relation to the CV treatment (Figure 2C), these coverage rates increase at evaluation dates later than 80 DAS, however, at 60 DAS, they already showed rates above 0.80 (80%) of soil coverage, being similar to those verified by Wolschick et al. (2016). Likewise, when considering the BO+CV (Figure 2E) and WO+CV (Figure 2H) treatments, there is an increase in soil cover rates up to 75 DAS and a subsequent reduction in these rates. Therefore, maintaining soil cover rates in late assessments, in relation to other treatments composed of a mix of cover crops, may be associated with the later development of the CV component (Krenchinski et al., 2018).

Another point that has a direct effect on maintaining water availability in the soil is the decomposition dynamics of each plant species. The cultivation of the different oat species evaluated tends to have a longer period of residue residence in the soil compared to the cultivation of forage turnip and common vetch (Ziech et al., 2015), due to a higher C/N ratio. The average C/N ratio value for oats is 30:1 (Cassol et al., 2023), for common vetch it is 14:1 (Cassol et al., 2023) and for forage turnip it is 20:1 (Cherubin et al., 2022). For oat species, dry phytomass ranged between 4,500.00 and 4,800.00 kg ha-1 for black oat (Figure 3A) and white oat (Figure 3B), respectively.

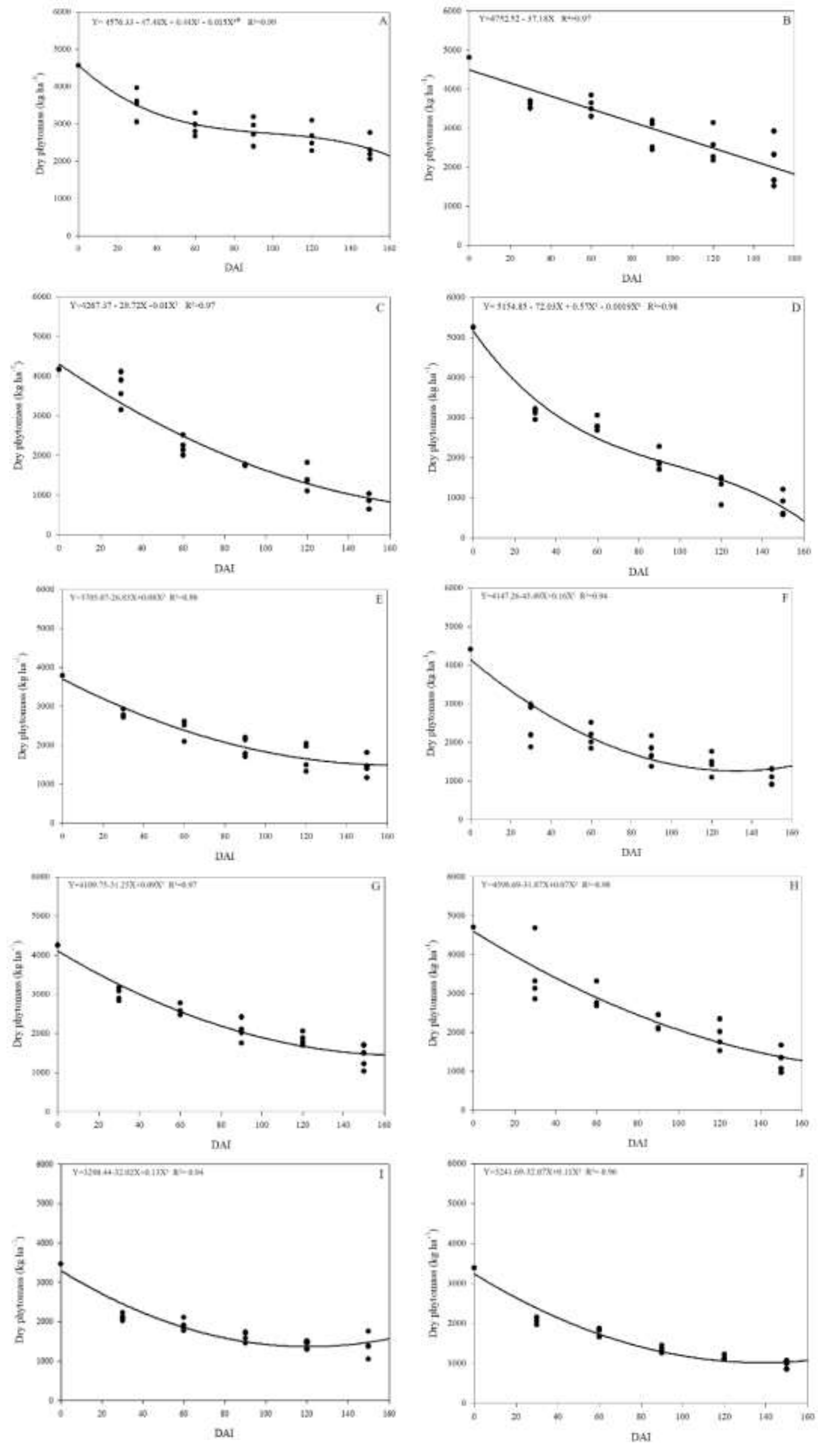

Figure 3. Decomposition curve of dry matter phytomass, using the litter bag methodology of Black oats (3A), White oats (3B), Common vetch (3C), Forage turnip (3D) in single cultivation and in a mix of cover crops Black oats + Common vetch (3E), Black oats + Forage turnip (3F), Black oats + Common vetch + Forage turnip (3G), White oats + Common vetch (3H), White oats + Forage turnip (3I), and White oats + Common vetch + Forage turnip (3J), Santa Maria, RS, 2023. *All equations plotted in the graphs are significant at a 5% probability of error.

After a 150-day period of exposure of these materials, the cultivation conditions showed a maintenance of plant material as 51.11% and 43.83%, respectively. The decomposition dynamics of black oats can be explained by a cubic regression model, initially presenting a more pronounced reduction in soil cover due to the decomposition of black oat leaf content, in an intermediate period a moment of stability in the maintenance of soil cover and in the final evaluation period, a greater reduction in the percentages of soil coverage due to the remaining content being weakened by climate action and microorganisms that act to decompose plant material. While in the case of white oats a linear regression model is used. Doneda et al. (2012), when working with oats and other cover crops, obtained values of less than 40% of remaining plant material in a similar period of time. These variations may occur due to the availability of nutrients in the soil, such as N, microbial activity, and its relationship with organic matter and water availability (Peña-Peña & Irmler, 2016).

In relation to common vetch (Figure 3C) and forage turnip (Figure 3D), as they are species from other families that have a lower C/N ratio than grasses, they presented different plant residue decomposition dynamics (Ntonta et al., 2022). This can be observed in the common vetch decomposition curve, which follows a quadratic model. Initially, there was a 4,100.00 kg ha^{-1} phytomass input, and there was a final percentage of 21.5% of phytomass in soil coverage after 150 days after the litter bag installation. In the case of the forage turnip dry phytomass decomposition, the cubic model was used, showing behavior similar to that observed in relation to black oat. Where there was the addition of values greater than 5200 kg ha^{-1} of dry phytomass, with only 15.86% of plant residues present on this date 150 days. In a work reported by Heinz et al. (2011), they observed that 75 days after managing the forage turnip, only 31% of the initial dry phytomass remained.

When observing the dynamics of dry matter phytomass decomposition of treatments with a mix of cover crops (Figure 3E, 3F, 3G, 3H, 3I, and 3J), we note in all of them that the treatments with a mix of plants were adequate to significant quadratic models, where they presented coefficients of determination equal to or greater than 0.94. Observing the final percentages of dry phytomass in soil cover between the mixes, the highest values were observed in the WO+FT treatment, with 39.8% after 150 days of exposure to the cultivation environment, with the others having intermediate values. Among the mixes, the treatment that presented the lowest values was BO+FT, with 26.29%, for values intermediate to treatments in direct cultivation, corroborating what was verified by Ziech et al. (2015). We observed that between the BO and WO treatments of the Poaceae family, higher final percentages were found in relation to the CV and FT treatments, in pure cultivation, which presented lower final percentages.

Therefore, we verify that the use of cover crop mixes results in a greater longevity of dry phytomass in soil cover in relation to CV and FT in single cultivation. This is the case reported by Heinrichs et al. (2001), where the association between common vetch and oats presented lower volumes of dry matter phytomass, but there was an increase in the persistence of crop residues on the soil surface, possibly due to the higher C/N ratio in oat plant residues. Therefore, there is a promising alternative in the use of a mix of plants in relation to the single cultivation of cover crops.

Conclusion

Forage turnip has a high capacity for vegetative development, presenting rapid development and soil coverage, with 79% coverage at 45 days after sowing. The common vetch crop showed lower development in the early period and greater soil coverage in the late period, with 84% coverage at 90 days after sowing and is preferably used in a mix of plants for soil coverage.

The maintenance percentage of dry matter phytomass in soil cover, at the end of the 150-day period, was highlighted for the black oat and white oat crops, and the presence of grasses in the cover crop mix is important for soil protection. The decomposition curve with mix behaves intermediately between grass crops or forage turnip and common vetch.

The forage turnip crop stood out with production in single cultivation and in a mix of cover crops with its participation. And the two mixes BO+FT and BO+CV+FT, presented an average dry matter phytomass volume that did not differ statistically from that of forage turnip, in both years.

Recommending the exclusive cultivation of the species that meets the rural producer's objective.

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