Advances in Weed Science
formerly Planta Daninha

RESEARCH ARTICLE

Integrated weed management strategies in a long-term crop rotation system

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Abstract: Background: Diversified crop systems provide several advantages for crop production and the agricultural ecosystem. In contrast, growing the same crop for consecutive years increases weeds, insects, and diseases issues, adding further cost to crop production owing to their management.

Objective: The objective was to evaluate the effects of six different winter cover crops and compare the impacts of a diversified rotation system in contrast to the succession system, combined with three different post-emergence herbicide management looking up to soybean yield, aboveground mass production, and weed density impact.

Methods: The experiment was performed over 2014 to 2018, using a randomized block design with four replications. Cover crop treatments were 1) fallow 2) wheat 3) rye 4) rye + turnip 5) rye + vetch 6) black oats. At the time of cover crop termination, weed density was counted and aboveground mass was measured. The crop rotation system was an alternated soybean and corn using three different post-emergence herbicide treatments, and the succession system was soybean each year. When a significant effect was observed after test F, the Tukey test ($p \leq 0.05$) was applied to compare treatment effects.

Results: Rye + vetch as a cover crop, rotation system, and herbicide usage showed a higher impact on weed density. Rye + turnip has produced more aboveground biomass. Soybean yield was higher after wheat.

Conclusions: Cover crops implementation, crop rotation system, and herbicide usage have increased biomass production and crop yield, and reduced weed density showing integrated weed management as a key strategy for production systems.

Keywords: Cover crop; Rotation; Herbicides; *Glycine max* (L) Merrill; *Zea mays* L.; Roundup Ready® system

Journal Information:
ISSN - 2675-9462
Website: http://awsjournal.org
Journal of the Brazilian Weed Science Society

How to cite: Rudell EC, Zanrosso BA, Frandaloso D, Giacomini AJ, Spadotto DV, Vargas L, Nunes AL, Santos FM. Integrated weed management strategies in a long-term crop rotation system. Adv Weed Sci. 2023;41:e020220053.
https://doi.org/10.51694/AdvWeedSci/2023;41:00026

Approved by:
Editor in Chief: Carlos Eduardo Schaedler
Associate Editor: Grace Bolfrey-Arku

Conflict of Interest: The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Received: August 6, 2022
Approved: November 30, 2022

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1. Introduction

No-till is considered one of the most appropriate techniques for the sustainability of Brazilian agricultural systems (Monteiro et al., 2019). Another vital goal for achieving management success consists of crop rotation in the same area; thus, plant species just return to the same place after remaining in a period occupied by other crops (Barbieri et al., 2019). On the other hand, succession crops represent the same crop sequence for several years, increasing the number of potential species (weeds, pests, and diseases) that can interfere with crop yield and raise productive costs (Wozniak, 2019).

Farmers lack of a holistic approach to the production system, which maintains the view that cover crops do not return for their establishment costs, renders farmers to look up for immediate income. Thus, these fields remain fallow during specific periods, – usually during the winter – resulting in low biomass production, soil degradation, and increasing weed number, which may select resistance biotypes by herbicide selection pressure (Adami et al., 2020; Pacheco et al., 2017). The higher weeds' density and diversity in these fields and their direct impact on crop yield is, in fact, an increasingly evident problem.

Owing to the advent of transgenic soybeans with roundup-ready[â] technology (RR) introduced in Brazil in 2005, the use of the glyphosate herbicide has increased exponentially, through the versatility of weed management that it has brought to farmers, as well as the costs reduction, being the most used herbicide to date (Silva et al., 2009). Over time, the performance of this herbicide has been reduced by the increased frequency of resistant weed species to its mechanism of action, resulting in tough and increase costs to manage. Hence, herbicide combinations have become the base for weed management, but they cannot keep up when compared to weeds' ability to develop resistance to herbicide mechanisms of action (Heap, Duke, 2018; Green, 2016).

From this perspective, integrated weed management requires farmers to use more than chemical methods to control weeds successfully. For example, cover crops implementation between cash crops, grown isolated or in mixtures, can bring umpteen benefits to the production system (Sso Miguel et al., 2018). In Southern Brazil, wheat *(Triticum aestivum* L.) is a winter crop option that can profit farmers and increase soybean yield in a row (Lamego et al., 2013). In more complex systems, corn (*Zea mays* L.) implementation allows even more herbicide rotation and increases biomass production, and consequently, can raise yields to upcoming crops, turning it into the best option for contributing to integrated management when looking for weed handling besides herbicide (Franchini et al., 2011; Balbinot et al., 2008).

The constant search for integrated weed management tools justifies carrying out studies that can help agriculture-related professionals expand their knowledge to weed management. In this context, studying different set systems can provide further information for greater use of resources, achieving greater efficiency, and ensuring the potential yield of crops. Thus, this research aimed to evaluate the effect of different cover crops in the winter, and a rotation crop and herbicide system implementation to compare with succession systems, as well as their interactions regarding soybean crop yield, aboveground mass production, and the impact on weed density.

2. Material and Methods

2.1 General experiment description

This research study was performed over 2014 to 2019 in Sertao, the Rio Grande do Sul State/Brazil. According to Köppen & Geiger classification, the regional climate is characterized as Cfa - subtropical humid. The annual average temperature is 18.3 °C, whereas the average yearly precipitation is 1,907 mm, at 670 meters above sea level. Soil is classified as Deep Dystrophic Red Nitossoil, with 49% of clay and 2.2% of organic matter, according to soil collection and analyses shown in Table 1.

2.2 Experimental design

The experimental design was a completed randomized block with four replications, in a factorial arrangement being Cover crops X Crop system X post-emergence herbicides (6x2x3). Cover crop treatments during the winter were: 1) Fallow; 2) Wheat (*Triticum aestivum* L.) 350 plants m^{-2}; 3) Rye (*Secale cereale* L.) 210 plants m^{-2} + Turnip (*Raphanus sativus* L.) 50 plants m^{-2}; 4) Rye 210 plants m^{-2} + Vetch (*Vicia sativa* L.) 60 plants m^{-2}; 5) Rye

Table 1 - Chemical and physical soil analysis

H2O	mg/dm³			cmolc/dm³				% (M/V)	
pH	P	K	Al	Ca	Mg	H + Al	CEC (pH 7.0)	O M	CLAY
5.6	21.1	26.5	0	5.74	2.35	3.35	12.64	2.2	49

Table 2 - Meaning of the F test, on soybean yield and weed density

Factors	Productivity	Weed Ds.	Dry matter
Crops	**	**	**
Rotation/succession system	**	**	**
Herbicides	**	**	**
Winter cover crops	**	**	**
Crop x rotation/succession system interactions	**	**	**
Crop x herbicide interactions	**	**	Ns
Crops x winter cover crops interactions	**	**	**
Rotation/succession system x herbicides interactions	**	**	Ns
Rotation/succession system x winter cover crops interactions	Ns	**	**
Herbicide x winter cover crops interactions	**	**	**
Crop x rotation/succession system x herbicides interactions	**	**	**
Harvest x rotation/succession system x winter cover crops interactions	**	**	**
Crop x herbicide x winter cover crops interactions	**	**	**
Rotation/succession system x herbicides x winter cover crops interactions	Ns	**	*
Crop x rotation/succession system x herbicides x winter cover crops interactions	**	**	**

**: significance level of p ≤ 0.01 *: significance level of p ≤ 0.05; ns: not significant

350 plants m^{-2}; 6) Oats (*Avena sativa* L.) 350 plants m^{-2}. During the summer, the rotation system has grown corn every other year, and the succession system has grown soybean each year. Post-emergence herbicides were sprayed 30 days after soybean/corn emergence. Treatments were: 1) no herbicide; 2) glyphosate (1,080 g a.i. ha^{-1}) 3) glyphosate (1,080 g a.i. ha^{-1}) + chlorimuron-ethyl (20 g a.i. ha^{-1}) in soybean or 3) glyphosate (1,080 g a.i. ha^{-1}) + atrazine (2,500 g a.i. ha^{-1}) in corn. Each experimental plot was 25 m² range.

2.3 General management, sample collection, and spray details

Cover crop treatments were sown with a seeding/fertilizer (Semeato® 15/17), with 17 seed lines spaced 0.17 m between them. On the day of wheat harvest, winter cover crop evaluation was aboveground mass collected at soil level in 1 m² from each plot, as well as counting weeds present in the same area. Cover crop samples were placed in an oven at 65 °C until a constant mass was obtained. To eradicate the cover crop treatments, standard control throughout the area was performed using Glyphosate (1,080 g a.i. ha^{-1}) + 2,4-D amine (1,005 g a.i. ha^{-1}), followed by a booster sequential application of paraquat (400 g a.i. ha^{-1}) about 14 days after the first application, to completely control the coverage.

All herbicide management was performed with a backpack sprayer pressurized by CO_2, using the spraying nozzle model TeeJet XR110015 spaced 0.5 m between them, at 3.0 bar, constant velocity, and a volumetric flow of 180 L ha^{-1}. For corn and soybean sown, was used the sower/fertilizer Kuhn® PG PLUS 700, with seven seed lines spaced 0.45 m between them. Soybean cultivars used were BMX® Ativa RR, NS 5959 IPRO, and NS 4823 RR in 2014/15, 2016/17, and 2018/19, respectively. Corn hybrids grown were Pioneer® 30F53 in 2015/16 and Agroeste® AS1666 in 2017/18. Crops density followed the recommendations of each cultivar/hybrid used for the specific region. Fertilization was based on the Brazilian Society of Soil (2004) recommendations.

2.4 Data analyses and climate details

Productivity data from soybean and corn were corrected to 13% humidity. Weed density was expressed in plants m^{-2}. Aboveground biomass production during the winter period was measured in kg ha^{-1}. Crops were manually harvested in a representative area of 6.75 m², which means three lines spaced at 0.45 m and 5 m in length, keeping out all plot edges.

For the soybean yield parameter, 2014/2015, 2016/2017, and 2018/2019 cycles were analyzed, whereas 2015/2016 and 2017/2018 were not evaluated, once there was corn on the plots that evaluated the effect of crop rotation. Corn yield data are not presented and discussed. For weed density (m^{-2}) and aboveground biomass production (kg ha^{-1}), five years were considered for statistical analyses. Data were submitted to variance analysis (ANOVA) by the F test, using the ASSISTAT 7.7 software (Silva, Azevedo, 2016), and when a significant effect was observed, they were submitted to the Tukey test ($p \leq 0.05$) to treatments means comparison.

The climatological weather data (1981–2010), referring to the average monthly precipitation and the accumulated precipitation in each month from 2014 to 2019 were provided by the National Institute of Meteorology (Instituto Nacional de Meterologia, 2020), based on the nearest meteorological station, 83914, located in Passo Fundo/RS.

3. Results and Discussion

3.1 Weed population

Weed management is considered a key point for agricultural intensification (Petit et al., 2015). Significant effects on weed population were observed regarding which crop was used during the summer, the management system (crop rotation or succession), herbicides, and cover crop treatments, as well as the interaction between these factors (Table 2). Fallow as a winter treatment has allowed the highest incidence of weeds during all years, particularly in 2017 (187 plants m^{-2}), which also produced the lowest aboveground biomass (Table 3). The lower density of weeds in 2014 is explained by the experiment implementation, presenting a reduced density of seeds on the soil seed bank, which was naturally fed over the years, bringing the highest weed incidence during 2017.

A high incidence of weeds was observed in the crop succession system (Table 3). Conversely, the crop rotation system has reduced weed density over the years. The continuous use of crop succession results in repeated exposure of weeds to a set cycle of ecological and agronomic conditions that increase weed infestation and promote the evolution of resistance, thereby interfering with crop productivity. Crop rotation modifies pesticide usage, sowing, and harvest dates and crops. As a whole, these actions are more effective at suppressing weeds than just increasing crop diversity, potentially reducing weed density by up to 65% (Weisberger et al., 2019). There is a limited effect on weeds' biomass suppression when each practice is taken independently, but outstanding results could be reached by combining a multi-tactic approach (Derksen et al., 2002; Adeux et al., 2019).

The association of rye + turnip was more effective in suppressing weeds, although it was not statistically different from oats, which also exhibited high suppressive potential (Table 3). The lower incidence of weeds can be inversely related to the amount of aboveground biomass produced by the winter treatment (Table 4), which provides a significant amount of remaining straw that in addition to protecting the soil, reduces weed emergence (Balbinot et al., 2008). Even producing lower biomass when compared with

Table 3 – Weed density (weed number/m^{-2}) on cover crop treatments at termination time

Factors	Growing season					
Winter cover crops	2014	2015	2016	2017	2018	Average
Fallow	77.3 aE	111.1 aC	89.9 aD	187.2 aA	125.9 aB	118.3 A*
Wheat	7.2 bA	10.3 bA	3.7 bB	2.2 bB	0.8 cB	4.8 B
Rye + turnip	0.3 dA	0.1 cdA	0.2 cA	0.1 bA	0.3 cA	0.2 B
Rye + Vetch	4.9 bcA	3.4 cAB	1.2 bcB	0.6 bB	3.4 cAB	2.7 C
Rye	7.3 bA	9.5 bA	0.6 bcB	0.9 bB	8.7 bA	5.4 B
Oat	2.3 cdA	0.0 dA	0.1 cA	0.6 bA	1.8 cA	1.0 D
Herbicides						
No herbicides	15.5 bD	20.3 bC	22.3 cA	35.7 aA	25.3 aB	23.8 A
Glyphosate	15.8 bD	25.8 aB	13.4 eB	29.5 bA	22.3 bC	21.3 B
Glyphosate + chlorimuron-ethyl	18.4 aC	21.1 bB	12.1 dB	30.6 bA	23 bB	21.0 B
Systems						
Succession	28.6 aC	41.5 aA	28.4 aC	36.2 aB	36.8 aB	34.3 A
Rotation	4.5 bC	3.3 bC	3.4 bC	27.6 bA	10.2 bB	9.8 B
Average	16.6 c	22.4 b	15.9 c	31.9 a	23.5 b	
Factors	**Herbicides**					
Winter cover crops	**No herbicides**	**Glyphosate**	**Glyphosate + Chlorimuron-ethyl**	**Average**		
Fallow	119.7 aA	118.3 aAB	116.9 aB	118.3 A		
Wheat	11.2 bA	2.1 cB	1.2 cB	4.8 B		
Rye + turnip	0.4 eA	0.1 cA	0.1 cA	0.2 D		
Rye + Vetch	3.5 dA	2.1 cA	2.5 bcA	2.7 C		
Rye	7.0 cA	4.7 bB	4.5 bB	5.4 C		
Oat	1.1 deA	1.0 cA	0.8 cA	1.0 D		
Systems						
Succession	36 aA	34.5 aB	32.4 aC	34.3 A		
Rotation	11.6 bA	8.3 bC	9.6 bB	9.8 B		
Average	23.8 a	21.4 b	21.0 b			
Winter cover crops	**Systems**					
	Succession		**Rotation**		**Average**	
Fallow	180.6 aA		56 aB		118.3 A	
Wheat	9.2 bA		0.5 bB		4.8 B	
Rye + turnip	0.3 dA		0.1 bA		0.2 D	
Rye + Vetch	5.2 cA		0.2 bB		2.7 C	
Rye	9.9 bA		1 bB		5.4 B	
Oat	0.7 dA		1.2 bA		1.0 D	
	34.3 a		9.8 b			

CV: 18.24%

*Classification with lowercase letters in columns and uppercase letters in rows, and the Tukey test was applied to the level of p≤0.05 significance

rye + turnip, oats exhibited an effective weed suppressive capacity, probably because it has a lower decomposition rate, maintaining the soil covered for a more extended period, interfering with the emergence of new weed flows, particularly light-sensitive seed species, such as *Conyza* (Agostinetto et al., 2000; Ottavini et al., 2019).

Plots without post-emergence herbicide during the summer (Treatment 1) showed high weed density during the winter, showing the quick system response to a farmer management gap. Winter fallow under glyphosate + chlorimuron-ethyl post-emergence treatment during the summer has reduced weed density by 12%. Characteristics such as emergency fluctuations, soil-water availability, solar radiation, and temperatures are essential and show specific influences on each weed species and its seeds' physiological condition, dormancy, depth, and farm management (Lage et al., 2017; Oliveira Jr. et al., 2011). However, herbicide management implementation reduces weed density, and glyphosate used alone or in associations shows good impacts on weed control and its further seed production rate (Ramires et al., 2010).

Ryegrass (*Lolium multiflorum* L.) infestation significantly reduces during winter treatments after corn, even on fallow. Less ryegrass density was also counted after glyphosate + atrazine treatment on corn. Important factors about it should be the earlier corn season compared with soybean and pre-emergence herbicide implementation, once atrazine is an essential and an efficient alternative in corn with direct effects on weeds' seed bank species as *Lolium* (Beckie et al., 2020; Piasecki et al., 2020; Barroso et al., 2021). Besides it, long-term and repeated pre-emergence herbicides could maintain weed density at a low level (Gao et al., 2019). Furthermore, a greater amount of crop residues which increases biological activity and intensifies seed decomposition in the soil could be directly related to the low density of ryegrass weed (Siewerdt et al., 2007).

Concerning the herbicides used, the crop rotation system obtained low weed density when the herbicide glyphosate was used in isolation, unlike the succession system, when glyphosate + chlorimuron-ethyl management was used. Crop rotation systems have shown a lower weed density when compared to succession systems. In contrast, the same does not occur in treatments where the population was larger and more diversified in species and flows when herbicide association achieves better results compared to glyphosate-isolated use. The highest weed density was counted at no post-herbicide treatment. Cover crop treatments show a similar result to weed density, except for fallow treatment (Table 3).

In the long-term view, agricultural systems that produce less biomass result in increased weed infestation over time and improve weed source on soil bank, based on species' exponential reproduction characteristics, besides seed-related factors such as longevity, dormancy, and high dispersion, which ensure the regenerative potential of each species to being present and competitive with crops (Monquero, Christoffoleti, 2005; Balbinot et al., 2008). Once crop diversity implementation determines characteristics such as sowing date, timing, herbicide mode of action, period of competition, harvest date, and amount of crop residue, the crop rotation system enables diversification and limits weed pressure (Barzman et al., 2015; Lechenet et al., 2014; Adeux et al., 2019).

3.2 Cover crop aboveground biomass production and soybean yield

Treatment of rye + turnip in association increases aboveground mass production considering the average of the five years, with 6,754 kg ha^{-1}. In contrast, fallow has reached 2,178 kg ha^{-1} (Table 4). Do cover crops in the association is an efficient alternative regarding aboveground production and allows benefits related to soil conservation and its moisture, nutrient cycling, decreased weed development, and increased crop yield, which can reach up to 22% (Chahal, Van Eerd, 2017; Chalise et al., 2019).

Table 4 - Winter cover crop aboveground biomass production (kg ha^{-1}) at termination time

Growing season	Winter cover crops						
	Fallow	Wheat	Rye + turnip	Rye + vetch	Rye	Oat	Average
2014	2350 abD	6048 aB	6702 bA	6093 bB	5410 bC	5327 bC	5322 C*
2015	2706 aE	5354 bD	6755 bA	6239 bBC	5757 bCD	6620 aAB	5572 B
2016	2153 bE	6134 aD	8376 aA	7778 aB	8253 aAB	6693 aC	6565 A
2017	2165 bE	5984 aD	8292 aA	7802 aB	8318 aAB	6215 aC	6462 A
2018	1527 cC	2165 cB	3559 cA	3846 cA	3872 cA	2391 cB	2894 D
System							
Succession	2944 aF	5617 aD	6813 aA	6133 bC	6491 aB	5081 bE	5513 A
Rotation	1411 bD	4716 bC	6694 aA	6560 aA	6127 bB	6008 aB	5253 B
Herbicides							
No herbicide	2015 aD	5178 aC	6473 bA	6359 aA	5880 bB	5567 aB	5245 B
Gly	2202 aE	5114 aD	7128 aA	6340 aB	6398 aB	5617 aC	5466 A
Gly + clo	2316 aC	5209 aB	6660 bA	6342 aA	6650 aA	5451 aB	5438 A
Average	2178 e	5167 d	6754 a	6347 b	6309 b	5545 c	
System	**Growing season**						
	2014	**2015**	**2016**	**2017**	**2018**	**Average**	
Succession	4869 bC	5475 aB	6993 aA	6993 aA	3237 aD	5514 A	
Rotation	5774 aB	5668 aB	6136 bA	6136 bA	2550 bC	5253 B	
Average	5322 c	5572b	6565 a	6565 a	2894 d		

CV: 11.02%

*Classification with lowercase letters in columns and uppercase letters in rows, and the Tukey test was applied to the level of 5% significance

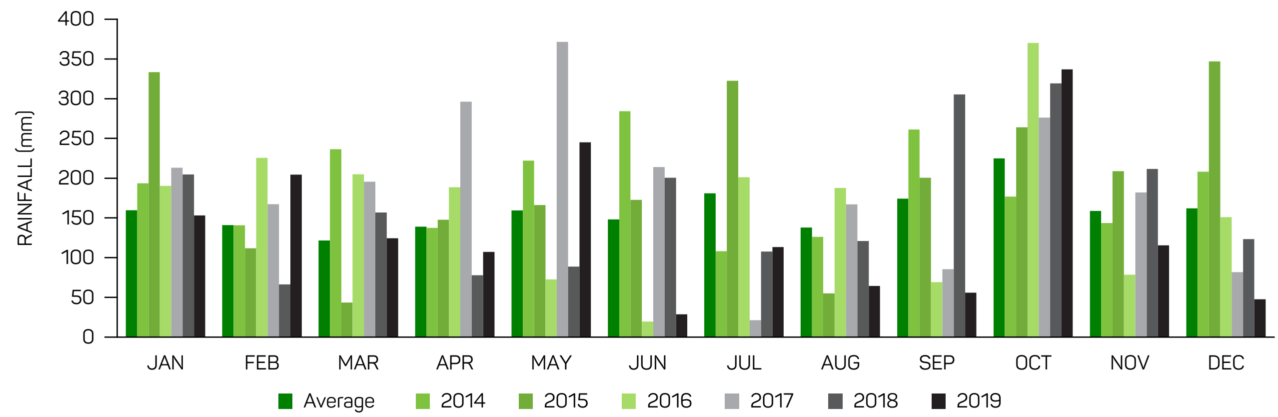

Figure 1 - Monthly precipitation during the three growing seasons (mm) (2014 to 2019) and the normal (1981–2010)

The highest soybean yield was obtained in 2016/17. Precipitation data show that this year accumulated higher rainfall concerning the average in January, February, and March, which are the most critical stages for achieving the highest soybean yield (Figure 1). The reproductive stage for soybeans (R1–R6) represents a sensitivity period to reduce yield potential by water shortage and achieve 35% more yield when water is correctly supplied (Montoya et al., 2017). Recent studies have shown that a 1% increase in rainfall during the vegetative period on C3 plants promotes a +0.27% yield (Makowski et al., 2020).

Crop and weed competition under low weed density (2014/15 and 2016/17) was similar to soybean yield, and the addition of chlorimuron-ethyl did not differ when compared with glyphosate. During 2018/19, as the climatic conditions provided more pronounced weed emergence flows, glyphosate + chlorimuron-ethyl resulted in higher crop yield owing to lower interspecific competition, due to efficient weed control.

The lowest soybean yield was found in the treatment without post-emergence herbicide (Table 5). Fields without weed control in post-emergence result in interspecific competition, which is the most cause of yield losses of up to 34% (Almarie, 2017). The 2016/17 season exhibited significant soybean yield (3,280 kg ha^{-1}) regarding a suitable climatic condition for crop development. The lowest soybean yield was founded in 2018/19, it was the season with rainfall shortage and an increased weed density present caused by previous weeds' reproduction, which increased the soil seed bank, with several flows during the soybean season.

Wheat as a winter cover crop has provided a high soybean yield, with a 3096 kg ha^{-1} average, followed by fallow, with 2,828 kg ha^{-1}. Other cover crop treatments did not differ between them by 5% significance. Cover crop treatments provided high soybean yield when post-emergence was used. Glyphosate as a post-emergence herbicide alone or in association with chlorimuron-ethyl has shown similar yield results. Herbicide association have increased effects after oat as a cover crop (Table 4).

When herbicides were not used in post-emergence soybean crops, there was no influence of the different coverages evaluated on their productivity, except for oat, in which soybean achieved a lower yield. Soybean yield was higher when cultivated in succession to wheat in treatments with the herbicide glyphosate post-emergence. When glyphosate and chlorimuron-ethyl were used together, soybean produced a higher yield when preceded by wheat and fallow treatment.

Fallow treatment has increased ryegrass density, once it can naturally reproduce in Southern Brazilian agricultural systems, being the most common winter weed. Ryegrass, as a natural cover crop, has produced a reasonable dry mass during the winter, which has allowed the permanent maintenance of the soil seed bank and its new flows every year when climate conditions turn favorable (Christoffoleti, López-Ovejero, 2003). In addition, ryegrass suppresses weeds such as horseweed (*Conyza* spp.) and increases soybeans grain number, resulting in higher soybean yield, turning ryegrass into a lousy presence (Lamego et al., 2013).

The crop rotation system has provided the highest soybean yield when compared to the succession system. Soybeans used each year have shown reduced yield, and one-year corn implementation was already sufficient to increase grain yield in soybean cultivation (Reis et al., 2014). Crop yield could be increased by 20% by taking advantage of each crop and its associated practices acting as a set of filters disrupting different phases of weed species' life cycle and when the time interval between the same crop is extended (Derksen et al., 2002; Adeux et al., 2019).

4. Conclusions

Cover crops use increased soybean yield, which was higher when preceded by wheat. Aboveground biomass

Table 5 - Soybean yield (kg ha^{-1}) under evaluated growing seasons, herbicide treatment, and cover crop

Growing season	Herbicides			
	No herbicide	Glyphosate	Glyphosate + Chlorimuron-ethyl	Average
2014/2015	1141 bB	3039 bA	3178 bA	2453 B*
2016/2017	3286 aB	4206 aA	4160 aA	3884 A
2018/2019	389 cC	2598 cB	2804 cA	1931 C
Winter cover crops				
Fallow	1533 abB	3449 bA	3501 abA	2828 B
Wheat	1748 aB	3825 aA	3714 aA	3096 A
Rye + turnip	1535 abB	3109 cA	3140 dA	2595 C
Rye + vetch	1647 abB	3097 cA	3291 bcdA	2678 C
Rye	1681 abB	3151 cA	3205 cdA	2679 C
Oat	1486 bC	3055 cB	3434 bcA	2658 C
System				
Succession	1672 aB	3114 bA	3244 bA	2677 B
Rotation	1539 aB	3448 aA	3517 aA	2835 A
Average	1605 c	3281 b	3381 a	
Winter cover crops	**Growing season**			
	2014/15	**2016/17**	**2018/19**	**Average**
Fallow	2875 aB	3558 cA	2049 bC	2828 B
Wheat	2821 aB	4102 aA	2364 aC	3096 A
Rye + turnip	2088 cB	3882 abA	1814 BCC	2595 C
Rye + vetch	2356 bB	3891 abA	1787 CC	2678 C
Rye	2173 bcB	4021 abA	1843 BCC	2679 C
Oat	2402 bB	3848 bA	1725 cC	2658 C
System				
Succession	2452 aB	3841 aA	1736 bC	2677 B
Rotation	2452 aB	3926 aA	2125 aC	2835 A
Average	2453 b	3884 a	1931 c	

CV: 15.36%

*Classification with lowercase letters in columns and uppercase letters in rows, and the Tukey test was applied to the level of 5% significance

was higher with rye + turnip, which, like oat, have the greatest reduced weed density. Crop rotation system – corn implementation – and glyphosate usage were significant in increasing soybean yield, aboveground mass production, and reducing weed density.

Author's contributions

All authors contributed equally to the design and writing of the manuscript.

Acknowledgments

The authors would like to thank the Federal Institute of Education, Science, and Technology of Rio Grande do Sul State (IFRS) for providing all the infrastructure needed to conduct this research study.

Funding

This research was funded by National Council for Scientific and Technological Development (CNPq) and the Research Support Foundation of Rio Grande do Sul State (FAPERGS).

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