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RESPONSES OF CORN HYBRIDS TO COVER CROPS ON GRAIN YIELD AND PRODUCTION COSTS

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ABSTRACT – Corn areas in Southern Brazil are generally managed without cover crops during the off-season, which can compromise both soil quality and the crop's productive efficiency. Furthermore, different corn hybrids may show distinct responses to management conditions, making their evaluation essential for proper recommendation to growers. Therefore, this study aimed to evaluate the effects of cover crops on the development, yield, and total operational cost of corn hybrids. The experiment was conducted in a randomized block design with four replications, in a 4 x 2 factorial scheme consisting of four corn hybrids (AS 1800 PRO3, DKB 242 PRO4, FS 395, and MG 377) and two cover crop mixes composed of grasses and legumes (RX 330 and RX 340). The crop yield components analyzed were: plant height, ear insertion height, chlorophyll content, leaf area, leaf area index, number of kernels per ear, thousand-grain weight, yield, and total operational cost. There was an interaction between hybrids and cover crops for traits such as plant height, thousand-grain weight, and yield. The results demonstrated that the mix with a higher presence of legumes provided higher yields for the AS1800 PRO3 hybrid, while the mix with more grasses resulted in higher yields for the FS 395 hybrid. The highest economic return was not associated with the treatments with the lowest operating costs, but rather with the corn hybrids that achieved the highest grain yields. The interaction between cover crops and genetic material influences corn yield and profitability in the Extreme South of Santa Catarina.

Keywords: economic return, soil management, *Zea mays*.

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Maize (*Zea mays* L.) is one of the most globally relevant agricultural crops, playing an essential role in human nutrition and livestock feed, as well as serving as a vital raw material for various industrial sectors. Consequently, growers face increasing pressure to achieve higher yields on the same or even smaller land areas, particularly given the 8.7% reduction in land allocated to maize cultivation (Giehl et al., 2024). Concurrently, there is a growing demand for sustainable agricultural practices directly linked to soil and water conservation (Shedekar et al., 2025).

In this context, off-season cover cropping has emerged as an established management strategy to improve soil health by enhancing biological diversity, recycling nutrients, improving aggregate stability, and reducing soil compaction, erosion, and environmental nutrient losses (Adetunji et al., 2020; Islam & Sherman, 2021; Islam et al., 2021; Çerçioğlu et al., 2025; Shedekar et al., 2025; Souza et al., 2025). These soil health improvements ultimately increase subsequent crop yields (Ruis et al., 2023). Studies also indicate that cover crop residue suppresses weed germination and emergence, thereby reducing pesticide reliance, lowering production costs, and mitigating environmental contamination (Quintarelli et al., 2022).

Several studies have investigated the effects of cover crops on the performance of maize, demonstrating that their influence depends on the species used and on environmental and management conditions (Giacomini et al., 2004; Sangoi et al., 2007; Hunter et al., 2019; Haruna & Nkongolo, 2020; Pott et al., 2021; Ruis et al., 2023). Maize production depends heavily on nutrient availability, particularly nitrogen (N), which is one of the primary constraints to yield. Accordingly, cover crops positively influence soil nitrogen dynamics. Legumes input greater amounts of N into the soil through biological nitrogen fixation, thereby enhancing soil fertility (Sainju et al., 2003; Haruna & Nkongolo, 2020). Conversely, using grasses as cover crops serves as an effective strategy to reduce nitrogen leaching and runoff losses, as grass species absorb larger quantities of N than legumes, produce higher biomass accumulation, and promote a more gradual nutrient release (Basche et al., 2014; Islam & Sherman, 2021).

In southern Brazil, cover crop composition, such as black oat, common vetch, oilseed radish, and their mixtures preceding maize, was shown to influence N accumulation and grain yield of the subsequent crop (Giacomini et al., 2004). Similarly, vetch increased maize productivity, although the magnitude of this response varied according to production management and N availability (Pott et al., 2021). Other studies have also shown that the effects of cover crop mixtures on maize are not always consistent. For example, multispecies cover crop mixtures did not necessarily increase maize yield, although residue characteristics, particularly the C/N ratio, were associated with maize performance (Hunter et al., 2019). These findings demonstrate that the effects of cover crops on maize are influenced by the composition of the preceding vegetation. Thus, intercropping grasses and legumes as cover crops represents an attractive strategy to optimize the complementary benefits of both plant families (Quintarelli et al., 2022; Hao et al., 2023).

Although cover cropping is well established as a fundamental practice for promoting agricultural sustainability and crop productivity, less attention has been given to the interaction between cover

crop systems and crop genetic materials (Haruna & Nkongolo, 2020; Islam & Sherman, 2021; Blanco-Canqui et al., 2022; Quintarelli et al., 2022; Hao et al., 2023). Different maize hybrids may respond differently to the environmental and nutritional conditions created by different cover crops due to genotype-by-environment interactions. Therefore, evaluating maize hybrids under cover crop mixtures may contribute to identifying genotype–management combinations that improve agronomic performance and economic efficiency. In this context, this study aimed to evaluate the effects of cover crop mixtures on yield components, grain yield, and total operational costs of different maize hybrids.

The experiment was conducted in the annual crop experimental field at the Instituto Federal Catarinense – Campus Santa Rosa do Sul, Brazil (29°05′46″ S, 49°48′45″ W; altitude 12 m), from September 2024 to March 2025. According to the Köppen climate classification, the regional climate is Cfa (humid subtropical), with a mean annual temperature of 19.5 °C and well-distributed annual precipitation averaging 1,709 mm (Climate Data, 2025). Daily precipitation and mean temperature during the experimental period are presented in Figure 1. Weather conditions throughout the growing season were favorable, with well-distributed rainfall and no water stress.

The soil at the experimental site is classified as a Gleissolo Melánico (Santos et al., 2018), corresponding to a Typic Endoaquept (Soil Taxonomy), with a clay content of 12%. Soil chemical properties were characterized from a composite sample collected at a depth of 0–10 cm. Soil chemical attributes indicated a pH in water of 5.4, SMP index of 6.7, organic matter of 3.5%, phosphorus (P) of 57.3 mg dm^{-3}, potassium (K) of 69 mg dm^{-3}, absence of exchangeable aluminum (Al^{3+}), calcium (Ca^{2+}) and magnesium (Mg^{2+}) concentrations of 6.4 and 2.8 cmolc dm^{-3}, respectively, cation exchange capacity at pH 7.0 (CECpH 7) of 9.8 cmolc dm^{-3}, base saturation (V) of 76.9%, and aluminum saturation (m) of 0.0%.

The trial was arranged in a randomized complete block design (RCBD) with four replications in a 4 x 2 factorial scheme, totaling 32 experimental units. Factor A comprised four commercial maize hybrids: AS 1800 PRO3 (Agroeste), DKB 242 PRO4 (Dekalb), FS 395 (Forseed), and MG 377 (Morgan). Factor B consisted of two cover crop mixtures (mixes): RX 330, composed of 62.5% of legumes and 37.5% of grasses; and RX 340, composed of 50% of each: legumes and grasses. The selection of maize hybrids was based on seed availability in the region and an interest in comparing the development and productivity of four cultivars widely used in the area. It is worth noting the scarcity of studies addressing the performance of these cultivars in the Extreme South of Santa Catarina.

The cover crops were sown in April of the previous growing season, prior to the sowing of the maize hybrids. Pre-sowing desiccation of the cover crops was performed using clethodim and glyphosate approximately 30 days before sowing the crop. Maize was hand-sown on October 28, 2024. Seeds were planted at a depth of 8 cm at a seeding rate of 3.6 seeds per linear meter with an inter-row spacing of 0.5 m, targeting a final plant population of 72,000 plants ha^{-1}. Each plot consisted of six 6-m-long rows. The usable area (10 m^2) comprised the four central rows, excluding one border row on each side and 0.5 m at each row end.

Nitrogen (N), phosphorus (P), and potassium

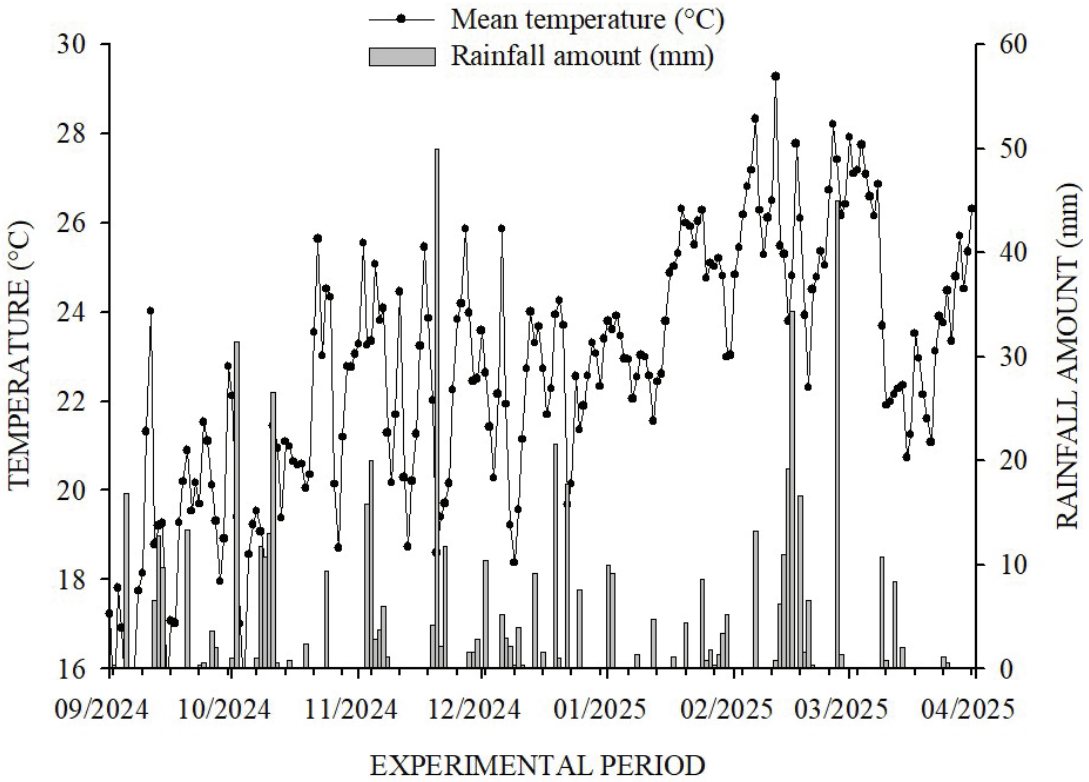


Figure 1. Rainfall amount and mean temperature values recorded during the experimental period (September 2024 to March 2025) obtained from the Inmet weather station in Araranguá, Santa Catarina, Brazil.
Fonte: Inmet (2025).

(K) fertilization was calculated based on soil test interpretation following regional fertilizer recommendations for maize in Rio Grande do Sul and Santa Catarina states (Manual […], 2016) to achieve a target yield of 12 Mg ha^{-1}. Total fertilizer applications amounted to 140 kg N ha^{-1}, 120 kg K_2O ha^{-1}, and 45 kg P_2O_5 ha^{-1}. At planting, monoammonium phosphate (MAP), potassium chloride (KCl), and controlled-release urea (Sulfammo) were applied to supply 45 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}, and 20 kg N ha^{-1}, respectively. Side-dress applications included 60 kg N ha^{-1} (Sulfammo) and 60 kg K_2O ha^{-1} (KCl) at the V3 growth stage, and 60 kg N ha^{-1} (conventional urea) at the V6 stage. Pest and weed management were carried out as needed throughout crop development.

Evaluated variables included plant height, stem diameter, leaf chlorophyll content, leaf area, leaf area index (LAI), mean kernel number per ear, 1000-kernel weight, grain yield, and total operational cost. Plant height was measured at the R1 growth stage (Ritchie et al., 1993) using a measuring tape from the soil surface at the base of the stem to the collar of the

uppermost fully expanded leaf. At the same growth stage, leaf chlorophyll content was evaluated on the ear leaf (indicator leaf) using a ClorofiLOG CFL1030 contact chlorophyll meter.

Leaf area was determined by measuring all leaves with greater than fifty percent green area on three representative plants per plot according to Sangoi et al. (2007):

$$LA = L \times W \times 0.75$$

where LA is individual leaf area (cm^2), L is total leaf length (cm), and W is maximum leaf width (cm). Individual leaf areas were summed to obtain total leaf area per plant (cm^2), converted to m^2, and used to calculate the Leaf Area Index (LAI) as the ratio of total plant leaf area to allocated ground:

$$LAI = \frac{\text{Total leaf area}(m^2) \times \text{ground area } (m^2)}{10{,}000\ (m^2)}$$

Harvesting was conducted manually in March 2025 across the four central rows of each plot, discarding three plants at each row end as border plants. Ears were harvested at approximately twenty-two percent grain moisture and manually threshed. Kernel number per ear was determined by direct counting, and one-thousand-kernel weight was determined by weighing sample replicates on an analytical precision balance. Grain yield was calculated from the total grain mass obtained from the usable area of each plot, converted to kg ha^{-1}, and adjusted to a standard moisture content of 130 g kg^{-1} (13.0%).

After crop harvest, additional soil samples were collected for soil bioanalysis (BioAS), following the methodology of Mendes et al. (2021), to assess biological soil quality via microbial activity indicators, comprising the Soil Quality Index (SQI) as presented in Table 1. Values observed in the sampling area fell within the range characteristic of biologically active soil, enhancing rhizosphere activity, nutrient cycling, and plant resource utilization efficiency.

Data were subjected to analysis of variance (ANOVA) at a significance level of $p \leq 0.05$. When significant treatment effects were detected, means were compared using Tukey's test ($p \leq 0.05$). Subsequently, a descriptive economic analysis of total operational costs was performed based on high-technology maize production cost guidelines developed by Giehl et al. (2024). As all treatments received the same management practices, differences in operating costs were attributed to the cost of the seeds and the specific costs of each cover crop mixture.

Results for plant height, 1000-kernel weight, and grain yield showed a significant interaction between maize hybrids and cover crop mixtures, indicating that hybrid performance varied depending on the crop environment provided by the cover crop residues.

Regarding plant height, among the hybrids cultivated following the RX 340 mixture, DKB 242 PRO4 exhibited the highest value (2.96 m) (Table 2). Following the RX 330 mixture, no significant differences were observed among DKB 242 PRO4, AS 1800 PRO3, and FS 395, all of which were superior to MG 377.

When comparing cover crop mixtures, hybrid AS 1800 PRO3 showed a height increase of 0.12 m when grown after RX 330, a mixture characterized by a higher legume proportion. This botanical composition tends to promote rapid N availability due

Table 1. Soil bioanalysis (0–0.10 m layer) of a GLEISSOLO MELÁNICO (Typic Endoaquept) in the annual crop area at the Instituto Federal Catarinense – Campus Santa Rosa do Sul, Brazil, using Embrapa's BioAS technology.

Beta-glucosidase	Arylsulfatase	Soil Quality Index		
		Biological	Chemical	Fertbio
35.0 (H)	188.0 (VH)	0.84 (VH)	0.9 (VH)	0.88 (VH)
Nutrient dynamics				
Cycling	Storage	Supply		
0.84 (VH)	1.00 (VH)	0.80 (VH)		

Soil bioanalysis index interpretation classes: VL = Very Low (0.00–0.20); L = Low (0.21–0.40); M = Medium (0.41–0.60); H = High (0.61–0.80); VH = Very High (0.81–1.00).

to a lower C/N ratio and faster residue decomposition rates, thereby enhancing early vegetative growth (Iamjud et al., 2026).

Conversely, DKB 242 PRO4 attained greater plant height following RX 340. This mix contains 12% cereal rye, a species that alters the temporal pattern of nutrient cycling and crop residue degradation (Haruna & Nkongolo, 2020). Consequently, this hybrid may have exhibited greater nutrient use efficiency throughout its growth cycle or superior adaptation to such residue conditions. The remaining hybrids maintained consistent plant height across both cover crop mixtures, indicating greater phenotypic stability or lower sensitivity to variations in the growing environment.

Regarding 1,000-kernel weight, the DKB 242 PRO4 hybrid showed the highest values when grown following the RX 340 mixture (Table 2). This result may be related to its genetic characteristics and adaptation to the management conditions of the experiment, in addition to the greater plant height observed under this treatment. Greater vegetative development may have favored assimilate accumulation and subsequent allocation to the grains during the grain-filling period.

In contrast, the MG 377 hybrid showed a 78-g reduction in 1,000-kernel weight when grown following RX 340, accompanied by lower plant height (Table 2). This response indicates that the performance of this hybrid differed under this growing condition, demonstrating that the response to cover crop mixtures may vary according to the characteristics of each hybrid.

The highest grain yield following the RX 330 mixture was achieved by hybrid AS 1800 PRO3 (14.37 Mg ha^{-1}), whereas the lowest yield was

Table 2. Plant height (m), 1000-kernel weight (g), and grain yield (Mg ha^{-1}) of maize (*Zea mays*) hybrids (AS 1800 PRO3, DKB 242 PRO4, FS 395 and MG 377) grown under no-till system following cover crop mixtures (RX 340 and RX 330) in the annual cropping area at Instituto Federal Catarinense – Campus Santa Rosa do Sul, Brazil.

	Plant height (m)		1000-kernel weight (g)		Grain yield (Mg ha^{-1})	
Cultivars	RX340	RX330	RX340	RX330	RX340	RX330
AS 1800 PRO3	2.81 Bb[1]	2.93 Aa	318.0 Ba	354.0 Aa	10.64 ABb	14.37 Aa
DKB 242 PRO4	2.96 Aa	2.80 Aa	410.0 Aa	382.0 Aa	9.12 ABa	8.09 Ca
FS 395	2.89 ABa	2.93 Aa	339.0 Ba	371.0 Aa	11.40 Aa	13.10 ABa
MG 377	2.50 Ca	2.43 Aa	301.0 Bb	379.0 Aa	8.26 Bb	11.58 Ba
CV (%)	2.14		7.24		9.87	
Factor A × B Interaction	0.0057		0.0240		0.0069	

(1) Means followed by the same letter do not differ significantly according to Tukey's test at 5% probability. Uppercase letters indicate comparisons within columns, whereas lowercase letters indicate comparisons within rows for each variable.

recorded for DKB 242 PRO4 (8.09 Mg ha^{-1}) (Table 2). This trend aligns with the plant height results, where AS 1800 PRO3 also demonstrated enhanced growth under RX 330, suggesting a positive response to higher initial N availability. Genotypes with greater N responsiveness at early developmental stages typically display enhanced vegetative growth and increased photosynthetic capacity, ultimately translating into higher grain yields (Moll et al., 1982).

However, when cultivated following the RX 340 mixture, hybrid FS 395 achieved the highest yield (11.40 Mg ha^{-1}), while MG 377 showed a yield reduction of 3.13 Mg ha^{-1}. Thus, the lower yield of MG 377, coupled with its reduced 1000-kernel weight under RX 340, reinforces the hypothesis that this hybrid requires higher initial N availability. These findings highlight genetic variation among maize hybrids regarding nitrogen use efficiency and the synchronization between N demand and supply throughout the growing cycle (Moll et al., 1982).

Neither cover crop mixture composition nor maize hybrid choice significantly influenced stem diameter, leaf area, leaf area index (LAI), or leaf chlorophyll content (Tables 3 and 4). Hybrids AS 1800 PRO3, DKB 242, and FS 395 exhibited higher ear placement height than MG 377, underscoring the strong genetic control over plant architecture (Cargnelutti Filho et al., 2020). Stem diameter remained similar across all treatments, an attribute typically associated with high heritability (Liu et al., 2022).

The absence of significant differences

Table 3. Ear placement height (m), stem diameter (cm), and chlorophyll content of maize (*Zea mays*) hybrids (AS 1800 PRO3, DKB 242 PRO4, FS 395, and MG 377) grown under no-till system following cover crop mixtures (RX 340 and RX 330) in the annual cropping area at Instituto Federal Catarinense – Campus Santa Rosa do Sul, Brazil.

Treatments	Ear placement height (m)	Stem diameter (cm)	Chlorophyll content
Cultivars			
AS 1800 PRO3	1.28 ^{ns}	2.40 ^{ns}	70.45 ^{ns}
DKB 242 PRO4	1.24	2.42	71.78
FS 395	1.27	2.42	70.20
MG 377	1.12	2.36	72.32
Cover crop mixtures			
RX 340	1.23	2.37	71.11
RX 330	1.23	2.40	71.26
CV (%)	4.59	4.75	6.40

(1) ^{ns} non-significant by the F-test at 5% probability.

in chlorophyll content, leaf area, and leaf area index indicates a comparable maintenance of the photosynthetic apparatus across treatments. The observed stability in chlorophyll index values may be related to soil biological quality, as elevated β-glucosidase (35.0 mg p-nitrophenol kg^{-1} h^{-1}) and arylsulfatase (188.0 mg p-nitrofenol kg^{-1} h^{-1}) activity levels indicate active carbon and sulfur cycling (Table 1). Combined with soil organic matter content exceeding 2.5%, these results suggest favorable soil conditions for nutrient cycling, leaf expansion, and carbon assimilation (Kuśmierz et al., 2023).

Kernel number per ear varied significantly among hybrids, with higher values recorded for AS 1800 PRO3 and FS 395 and lower performance for DKB 242 PRO4, consistent with patterns observed for grain yield and 1000-kernel weight (Table 4). Consequently, final grain yield was governed by both the genetic potential of the hybrids and the nutrient dynamics driven by the cover crop mixtures.

Economic analysis of the treatments revealed distinct differences among maize hybrid and cover crop combinations, demonstrating that maximum profitability was not driven by lower operational costs, but rather by the capacity of treatments to generate higher gross revenue through yield gains (Table 5).

The RX 330 + AS 1800 PRO3 treatment stood out with the highest yield in the experiment (14.37 Mg ha^{-1}). Consequently, it generated the highest gross revenue (BRL 17,049.91 ha^{-1}) and the highest gross margin (BRL 7,148.87 ha^{-1}). Although

Table 4. Leaf area (cm^2), leaf area index (LAI), and average number of kernels per ear of maize (*Zea mays*) hybrids (AS 1800 PRO3, DKB 242 PRO4, FS 395 and MG 377) grown under no-till system following cover crop mixtures (RX340 and RX330) in the annual cropping area at Instituto Federal Catarinense – Campus Santa Rosa do Sul, Brazil.

Treatments	Leaf area (cm^2)	LAI	Number of kernels per ear
Cultivars			
AS 1800 PRO3	5,083.52 ^{ns}	3.66 ^{ns}	570 ^{ns}
DKB 242 PRO4	4,484.25	3.23	322
FS 395	5,281.02	3.80	530
MG 377	5,403.46	3.89	454
Cover crop mixtures			
RX 340	5,053.07	3.64	449
RX 330	5,073.05	3.65	489
CV (%)	12.63	12.66	8.16

(1) ^{ns} non-significant by the F-test at 5% probability.

Table 5. Economic evaluation of maize (*Zea mays*) hybrids (AS 1800 PRO3, DKB 242 PRO4, FS 395 and MG 377) grown under no-till system following cover crop mixtures (RX 340 and RX 330) in the 2024/2025 cropping season.

Treatments	Operating Costs[1]	Gross Revenue[2]	Gross Margin[3]
	BRL per hectare (BRL^{-1})		
RX 330 + AS 1800 PRO3	9,901.04	17,049.91	7,148.87
RX 330 + DKB 242 PRO4	8,859.82	9,598.13	738.31
RX 330 + FS 395	9,964.39	15,536.78	5,572.40
RX 330 + MG 377	9,732.33	13,741.43	4,009.10
RX 340 + AS 1800 PRO3	9,032.57	12,620.82	3,588.25
RX 340 + DKB 242 PRO4	9,099.81	10,821.91	1,722.10
RX 340 + FS 395	9,570.00	13,525.61	3,955.61
RX 340 + MG 377	8,960.52	9,805.65	845.13

(1) Total costs of inputs and services in production. (2) Value obtained from production, assuming a price of BRL 71.15 per 60-kg bag. (3) Difference between gross revenue and total costs.

its operational cost was high (BRL 9,901.04 ha^{-1}), the substantial yield increase offset the production costs, yielding the greatest financial return. Conversely, the lowest economic returns were recorded for treatments involving DKB 242 PRO4, particularly when grown after RX 330. Despite having the lowest operational cost among all treatments (BRL 8,859.82 ha^{-1}), its yield reached only 8.09 Mg ha^{-1}, leading to the lowest gross revenue (BRL 9,598.13 ha^{-1}) and lowest gross margin (BRL 738.31 ha^{-1}). This finding demonstrates that reducing production costs does not guarantee profitability, as grain yield exerts a dominant influence on financial returns.

Overall, the economic evaluation confirms the agronomic findings, demonstrating that higher financial returns were achieved by treatments that attained superior grain yields (Table 5). Among the evaluated combinations, RX 330 + AS 1800 PRO3 and RX 330 + FS 395 proved to be the most promising options for maximizing cropping system profitability, whereas combinations involving hybrid DKB 242 PRO4 exhibited lower economic potential under the conditions tested.

Conclusion

The agronomic performance and economic response of maize hybrids were dependent on the composition of cover crop mixtures, which significantly affected both grain yield and farm profitability. Hybrid AS 1800 PRO3 achieved superior performance when cultivated following the RX 330 cover crop mix, whereas FS 395 performed best following RX 340. These findings demonstrate that the joint selection of maize hybrid and cover crop composition is crucial for maximizing crop performance and economic returns under the evaluated agroclimatic conditions.

Authors' Contributions

Conceptual Idea: Velho, L. A. S.; Rosa, E. F. F.; Nohatto, M. A.; Methodology design: Velho, L. A. S.; Rosa, E. F. F.; Siqueira, P. O.; Erdmann, L. F.; Data Collection: Velho, L. A. S.; Siqueira, P. O.; Luz, S.; Data analysis and interpretation: Velho, L. A. S.; Rosa, E. F. F.; Nohatto, M. A.; Siqueira, P. O.; Luz, S.; Erdmann, L. F.; Writing and editing: Velho, L. A. S.; Rosa, E. F. F.; Nohatto, M. A.; Siqueira, P. O.; Luz, S.; Erdmann, L. F.

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