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Multivariate analysis using a discriminant method for evaluating the techniques of weed management in soybean crop

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

HIGHLIGHTS

- Discriminant analysis identified differences among the management techniques assessed.
- Glyphosate provided better results with all cover crops.
- Chicory and quinoa cover crops were differentiated by the applied managements.

ABSTRACT

Background: The analysis of information generated from experiments involving different treatments, can be done by multivariate statistical analysis techniques, such as discriminant analysis, to analyze data obtained from predefined groups.
Objective: Verify, through discriminant analysis, the differences among cover crop (*Avena strigosa, Chenopodium quinoa, Cichorium intybus,* and fallow land) treatments with respect to main crop soybean yield.
Methods: For weed control, these cover crops were subjected to different management techniques, namely mowing, the application of glyphosate or the application of paraquat. The experimental design consisted of completely randomized blocks in a 4 × 3 × 2 factorial scheme, with four replications, consisting of the following factors: Factor A: (treatment) cover crops of *A. strigosa, C. quinoa, C. intybus,* and fallow land; Factor B: (management) plots were subdivided and treated with the application of paraquat or glyphosate, or the mowing of cover plants; Factor C: the plots were sub-subdivided and managed by one or two applications of a post-emergence herbicide. In order to evaluate the percentage of correct classifications of the different management techniques and treatments, a data matrix was elaborated for evaluation of variables relating to the soybean crop and the data were standardized by log - log 10 - log (n; 10). Multivariate analysis was performed using Fisher's linear discriminant method.
Results: Discriminant analysis selected four variables with discriminatory power relating to the *A. strigosa, C. quinoa, C. intybus* and fallow, which contributed to 100% of the explained variance.
Conclusions: Treatment with oats used as a cover crop provided higher soybean crop yield, whereas in terms of management, weed control using glyphosate provided the best results with all cover crops.

1 Introduction

Brazil has a long history of soybean production, and data indicate that the average yields of soybean crops increased from 1,748 kg ha^{-1} to 3,206 kg ha^{-1} during the period from 1976/1977 to 2018/2019 (Conab, 2020). This increase in productivity can be attributed to several factors, including genetic improvement, alteration in planting systems (conventional to no-tillage), soil management and conservation, and pest, disease, and weed control technologies (Domingos et al., 2015).

Among the different types of agricultural management, weed control is one of the most important technologies adopted to ensure satisfactory crop development. In this regard, in no-tillage systems, the use of soil cover crops can contribute to reducing weed growth and providing conditions conducive to the development of the main crop. The introduction of new cover crops with these characteristics and application of optimal management procedures is important for the continuity and further evolution of no-tillage systems (Motter and Almeida, 2015).

The agricultural use of systems that use soil and fallow crops or involve the cultivation of economically viable species, such as soybean in southern Brazil, or management of agricultural areas, has been responsible for maintaining the productivity of these areas for long periods (Resende et al., 2002). In order to perpetuate this evolutionary process, continuous studies are necessary to evaluate new varieties and species of cover crop plants that can contribute to realizing maximum productive potential and thereby benefit the main crop, either by improving soil conditions or with respect to weed control.

When analyzing these studies or experiments, several methodologies can be used to optimize the value of the information generated. In this regard, a particularly valuable approach is multivariate statistical analysis, mainly based on discriminant analysis, in which the data are already categorized into predefined groups (Sartorio, 2008).

Multivariate analysis is an important tool that can be used for an exploratory analysis of data comprising multiple variables, based on the grouping of samples according to similarity (from zero to one) or difference, and also facilitates the selection of variables of greater importance in the discrimination of pre-established groups or classes (Benites et al., 2010; Callegaro and Longhi, 2013; Kilca et al., 2015).

Multivariate techniques are often used by researchers in the rural and biological fields, and in the interpretation of databases in these areas (Ludwig and Reynolds, 1988; Gauch, 1991; Orlóci, 1991; Weirich Neto et al., 2006; Ferreira, 2008; Benites et al., 2010; Kent, 2012). These multivariate techniques have potential utility in the ordering of agricultural areas cultivated under different managements as a function of physical, chemical, and biological attributes, in order to evaluate the quality of soil and degraded substrates, as well as the productivity of cultivars (Pereira et al., 2014).

Discriminant analysis is a multivariate technique used when the dependent variable is categorical, which indicates the groups, and the independent variables are quantitative (metrics) (Ludwig and Reynolds, 1988; Hair et al., 2005; Johnson and Wichern, 2007; Ferreira, 2008; Lattin et al., 2011; Ribas and Vieira, 2011; Kent, 2012). It seeks to identify the variables that differentiate groups and thus enables predictions regarding new observation, identifying the most appropriate group to which it should belong according to its characteristics. To obtain these results, the analysis formulates discriminatory functions (linear combinations of variables) that will sort the groups by dependent variables and show their differences in an ordering plot (Fávero et al., 2009).

Accordingly, in the present study, we used discriminant analysis with the aim of classify and differentiating data relating to treatments using the cover crops oats, forage chicory, and quinoa, as well as fallow land, with application of the management techniques of mowing, the application of glyphosate or paraquat, and post-emergence weed control, with respect to soybean yield.

2 Material and Methods

The study was conducted in the agricultural year 2016/2017. According to the Köppen climate classification, the climate of the region is type Cfa - Subtropical climate, and is characterized by hot summers, infrequent frosts, and a tendency to rain in the summer months, although without a defined dry season. The average temperature during the coldest month is below 18 ºC (mesothermal), whereas that in the hottest month is above 22 ºC.

The soil in this region is classified as a Red Latosol, with clayey texture in the 0-20 cm layer. The chemical characteristics of the soil are as follows: pH ($CaCl_2$) 5.10; P (Mehlich^{-1}) 1.97 mg dm^3; K (Mehlich^{-1}) 0.43 $cmol_c$ dm^3; Ca (KCL 1 mol L^{-1}) 3.2 $cmol_c$ dm^3; Mg (KCL 1 mol L^{-1}) 1.8 $cmol_c$ dm^3; H + Al (pH SMP) 4.28 $cmol_c$ dm^3; SB (sum of bases) 5.43%; and V% (base saturation) 55.92%.

The experimental design consisted of randomized blocks with four replications conducted in a 4 × 3 × 2 factorial scheme. Factor A represented treatments with the cover crops of oats, forage chicory, and quinoa, and also fallow land. Factor B represented different management techniques, where the plots were subdivided and subjected to one of the following managements: application of paraquat at 400 g a.i. ha^{-1}, application of glyphosate at 1,200 g a.i. ha^{-1}, and mowing of the cover crops. Factor C represented post-emergent weed control, in which the plots were subdivided and received either one or two applications of post-emergent control herbicide.

With regards to factor A, each plot comprised an area of 53.6 m^2 (13.4 m × 4.0 m), whereas factor B and factor C sub-plots had areas of 17.84 m^2 (4.46 m × 4.0 m) and 8.92 m^2 (4.46 m × 2.0 m), respectively, giving a total experimental area of 857.6 m^2.

In order to implement the experiment, the area was prepared by plowing and levelling with a harrow to homogenize the soil and facilitate the sowing of cover crops, which was conducted manually using a haul. Subsequently, the seeds were covered with a rake to depths of approximately 3 to 4 cm for oats and 0.5 to 1 cm for forage chicory and quinoa. The fallow plots remained unseeded and the plants that subsequently emerged were derived from the pre-existing soil seed bank.

The sowing of cover species was performed on July 11, 2016, using 60 kg ha^{-1} of oats (Sá, 1995), 5 kg ha^{-1} forage chicory [based on studies carried out in Santa Catarina (Hanisch et al., 2013)], and 7.5 kg ha^{-1} quinoa (Spehar and Santos, 2002). The preceding crop was beans and no fertilization were used to plant cover crops. The treatments were applied on October 17, 2016.

At 53 days after the emergence (DAE) of soybean, weed species and their population densities were identified and determined, respectively, using the square inventory method in an area of 0.25 m². For each of the square in each plot, plants were identified by comparisons with the literature (Lorenzi, 2006).

Seeds of the soybean cultivar Pioneer 95R51 RR were sown on November 4, 2016, 18 days after the management of cover crops (according to treatment), using a no-tiller direct sowing system. Basal fertilization consisted of 415 kg ha^{-1} of 02-28-20 N-P-K formulated fertilizer. The soybean seeds were treated with the fungicides methyl thiophanate and fluazinam at doses of 200 mL c.p. for 100 kg of seeds, and the insecticide acetamiprid at a dose of 100 g c.p. for 100 kg of seeds. Harvesting of the crop was carried out on March 7, 2017 at 153 DAE.

Multivariate analysis with Fisher's linear discriminant method was used to classify and evaluate soybean crop yield, cultivated in plots under oat, forage chicory, quinoa, and fallow treatments, and subjected to different management procedures (mowing, application of glyphosate or application of paraquat, with post-emergent herbicide application). This analysis was also performed to classify and evaluate the soybean crop yield obtained from plots subjected to the aforementioned management techniques.

A data matrix containing 96 rows (24 replicates for each treatment) and 13 evaluation-dependent variables for soybean crops after the application of management techniques was elaborated. The variables were as follows: the numbers of hairy beggarticks (*Bidens pilosa*) (m²), gallant soldier (*Galinsoga parviflora*) (m²) and milkweed (*Euphorbia heterophylla*) (m²) individuals at 53 DAE of soybean; the percentage (%) straw cover at 53 DAE of soybean; leaf area at 22 DAE and 53 DAE of soybean; height at 53 DAE and 118 DAE of soybean; dry mass (DM) of soybean (kg ha) at 53 DAE; first pod insertion; number (No.) pods per plant; and the weight of 1,000 grains and yield (kg ha^{-1}) of soybean. These data were standardized using a 10-log (n;10) base logarithm. Analyses were performed using SPSS software © Copyright IBM Corporation, version 20 (IBM SPSS, 2011).

3 Results and Discussion

The discriminant analysis selected four variables with discriminatory power for the four treatments (oats, chicory, quinoa, and fallow), namely, the percentage of soil cover at 53 DAE of soybean, the height of soybean at 53 DAE, and the numbers of hairy beggarticks (m²) and milkweed (m²) at 53 DAE of soybeans, with statistical significance ($p<0.001$) (Table 1).

Three discriminant functions were selected, which represented 100% of the explained variance, with only the first discriminant function, representing 94.6% of the variance, being significant ($p<0.001$), due to the high chi-square value (164.560) and low Wilks's Lambda (0.164) (Table 2).

The three variables number of hairy beggarticks (m²) at 53 DAE of soybean, percentage soil cover, and soybean height at 53 DAE, were found to show significant weight in the first discriminant function, whereas the number of milkweed (m²) at 53 DAE

Table 1 - Variables selected to classify the experimental blocks and their respective statistics. Dois Vizinhos-PR, 2017

Stage	Inserted	Wilks's Lambda											
		Statistic	df1	df2	df3	Exact F				Approximate F			
						Statistic	df1	df2	Sig.	Statistic	df1	df2	Sig.
1	% coverage 53 DAE soybean	.534	1	3	92	26.764	3	92	.000				
2	Soybean height (cm) 53 DAE	.246	2	3	92	30.820	6	182	.000				
3	Hairy beggarticks (m²) 53 DAE soybean	.193	3	3	92					23.475	9	219.187	.000
4	Milkweed (m²) 53 DAE soybean	.164	4	3	92					19.269	12	235.763	.000

of soybean showed high weight in the second discriminant function, and the number of milkweed (m²) and percentage soil cover at 53 DAE of soybean, displayed average weight in the third function. The variables that were not selected in the analysis all showed low weights in the discriminant functions (Table 3).

Table 2 - Statistics for selection of the number of discriminatory functions. Dois Vizinhos-PR, 2017

Eigenvalues				
Function	Eigenvalue	% of variation	Cumulative (%)	Canonical correlation
1	3.966*	94.6	94.6	.894
2	.215*	5.1	99.7	.421
3	.011*	.3	100.0	.104
Wilks's Lambda				
Function testing	Wilks's Lambda	Chi-square	df	Sig.
1 to 3	.164	164.560	12	.000
2 to 3	.814	18.722	6	.005
3	.989	.998	2	.607

* The first three canonical discriminatory functions were used in the analysis.

Table 3 - Standardized canonical discriminant function coefficients. Dois Vizinhos-PR. 2017

	Function		
	1	2	3
Hairy beggarticks (m²) 53 DAE soybean	-.538	-.343	.268
Milkweed (m²) 53 DAE soybean	-.151	.930	.495
% coverage 53 DAE soybean	1.218	-.293	.439
Height (cm) 53 DAE soybean	.793	.361	-.164

The discriminant analysis revealed 63.5% correct classification (Table 4). For treatment 1 (oat cover crop), all evaluations of management techniques (24) were correctly classified. For treatment 2 (forage chicory cover crop), 18 evaluations of management techniques (24) were correctly classified. For treatment 3 (quinoa cover crop), 13 evaluations of the management techniques were correctly classified. For treatment 4, (fallow), only six evaluations of the management techniques were correctly classified. Poorly classified management techniques indicate that they are similar to the management of other treatments.

Of the 24 evaluations of the treatment techniques with forage chicory, four (34, 37, 39, and 40) should have been classified in the treatment with quinoa, because they showed similar results. Similarly, two (38 and 43) should have been classified in the fallow treatment. Of the 24 evaluations of quinoa treatment management techniques, four (49, 50, 51, and 69) were more similar to the results of treatment for forage chicory, and seven (53, 62, 65, 66, 70, 71 and 72) were similar to the fallow treatment results. Of the 24 management techniques associated with the fallow treatment, one (94) resembled that of the oat treatment, 10 (74, 76, 79, 80, 81, 83, 84, 88, 92, and 96) resembled those of forage chicory treatment, and seven (78, 82, 86, 89, 90, 91, and 95) resembled those of quinoa treatment.

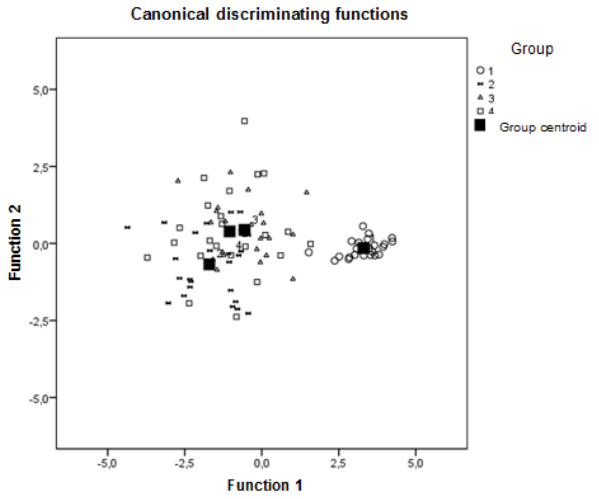
The ordering of management techniques in their respective experimental treatments showed that oats are equidistant from other crops (Figure 9). The oat cover crop is also homogeneous, with scores for the 24 evaluations of the management techniques close to the centroid, indicating 100% correct classification.

Table 4 - Percentage correct classification of assessments of management techniques in the respective experimental blocks. Dois Vizinhos-PR. 2017

Group			Association with expected group				Total
			1	2	3	4	
Original	Count	1	24	0	0	0	24
		2	0	18	4	2	24
		3	0	4	13	7	24
		4	1	10	7	6	24
	%	1	100.0	0.0	0.0	0.0	100.0
		2	0.0	75.0	16.7	8.3	100.0
		3	0.0	16.7	54.2	29.2	100.0
		4	4.2	41.7	29.2	25.0	100.0

63.5% of the original grouped cases were correctly classified.

In the other treatments (chicory, quinoa, and fallow) the scores of the management technique evaluations overlap with each other and their centroids are more similar. The scores for poorly classified management techniques exceeded the limits of their respective groups (Figure 1). In plots planted with forage chicory and quinoa cover crops or left fallow, and managed with mowing, application of glyphosate or paraquat, and with post-emergence herbicide application, the variables analyzed did not display large differences.



Group 1 Oats; Group 2 Forage chicory; Group 3 Quinoa; Group 4 Fallow.

Figure 1 - Classification of weed control management techniques in the respective experimental blocks, with corresponding centroid values. Dois Vizinhos-PR. 2017.

In contrast, the oat cover crop treatment showed significant differences, indicating considerable advantages with respect to soybean yield, with higher coverage, greater height, higher productivity (kg ha), and, notably, higher dry matter production (Figure 2).

These findings are consistent with those previously reported by Valicheski et al. (2012), who demonstrated that black oats yielded superior development results and promoted higher soybean yields when compared with turnip forage at different levels of soil compaction, providing yields higher than 3.5 tons ha^{-1}. With respect to the treatment with an oat cover, we found that the discriminant analysis did not provide functions that could classify the weed control management techniques (mowing, and the application of glyphosate, paraquat, and post-emergent herbicide), thereby indicating that there were no significant differences between these technique and that all of these were efficient (Figures 1 and 3).

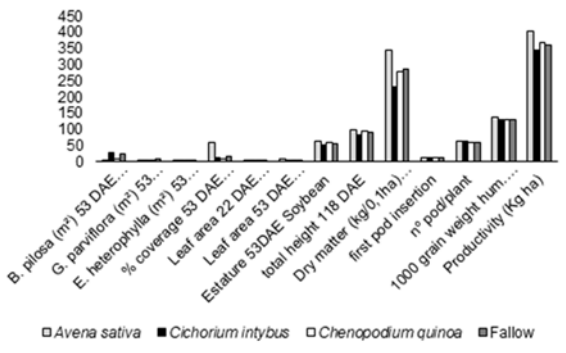


Figure 2 - Evaluation of efficiency variables among oats, forage chicory, quinoa, and fallow experimental blocks, with respect to the thirteen assessed variables. Dois Vizinhos-PR, 2017.

Discriminant analysis of the forage chicory crop treatment identified five variables, namely, soybean height, soybean leaf area, number of hairy beggarticks (m^2), percentage of soil cover (all at 53 soybean DAE), and first pod insertion, with discriminatory power. Two discriminatory functions were necessary to classify the management techniques to represent 100% of the variance, with the first function contributing 99.9% of the explained variance.

There was a 100% correct classification in all weed control techniques used for the soybean crop (mowing and the application of glyphosate or paraquat, all with application of post-emergent herbicide). The centroids of the three control groups are equidistant and well separated, indicating that these techniques produce different results for the variables analyzed (Figures 4 and 5).

For the quinoa cover crop, the discriminant analysis selected two variables with discriminatory power, namely, the number of hairy beggarticks (m²) and soybean height at 53 DAE. Two discriminatory functions were required to classify the management techniques to represent 100% of the variance, the first and second of which contributed 66.8% and 33.2% of the explained variance, respectively.

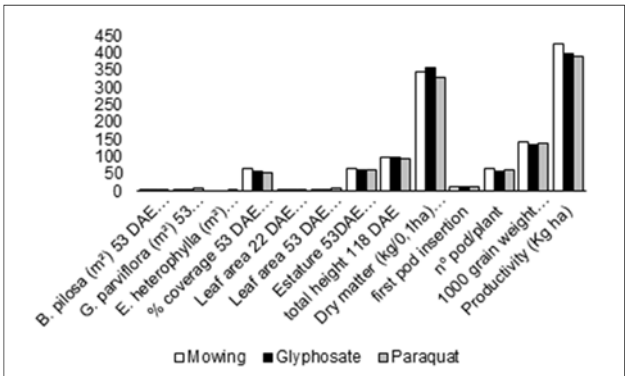
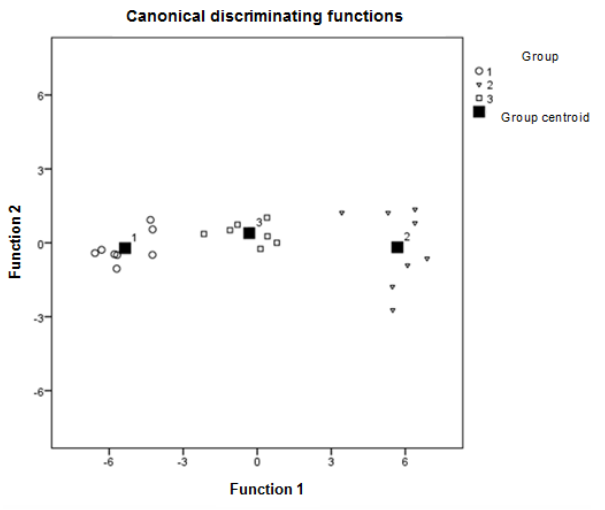
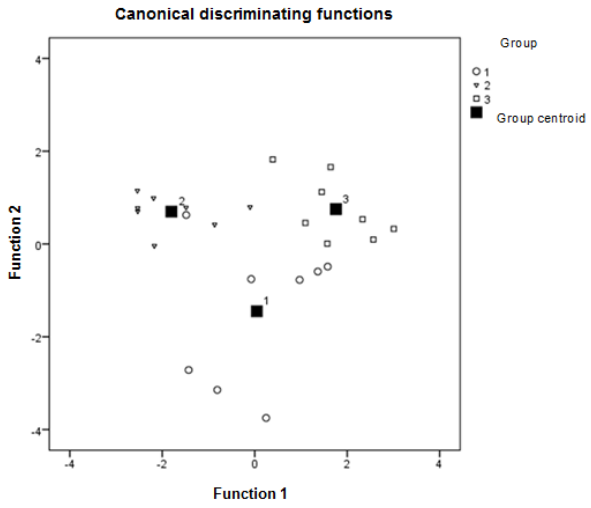


Figure 3 - Evaluation of the efficiency variables among different management techniques in weed control (mowing, application of glyphosate, and application of paraquat) with an oat cover crop. Dois Vizinhos-PR, 2017.



Group 1 Mowing; Group 2 Glyphosate; Group 3 Paraquat.

Figure 4 - Classification of assessments of weed control management techniques, with corresponding centroid values, for the forage chicory cover crop. Dois Vizinhos-PR, 2017.



Group 1 Mowing; Group 2 Glyphosate; Group 3 Paraquat.

Figure 6 - Classification of assessments for the respective weed control management techniques, with corresponding centroid values, for the quinoa cover crop. Dois Vizinhos-PR, 2017.

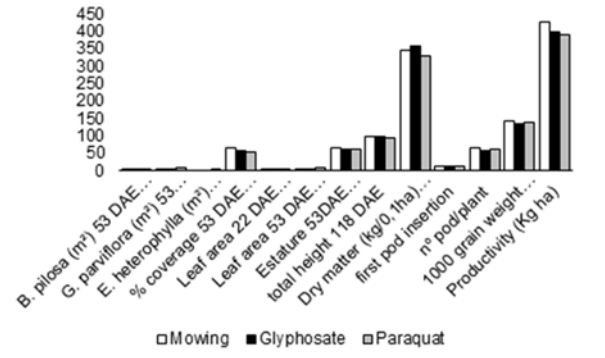


Figure 5 - Evaluation of the efficiency variables among different weed control techniques (mowing, application of glyphosate, and application of paraquat) for a forage chicory cover crop. Dois Vizinhos-PR, 2017.

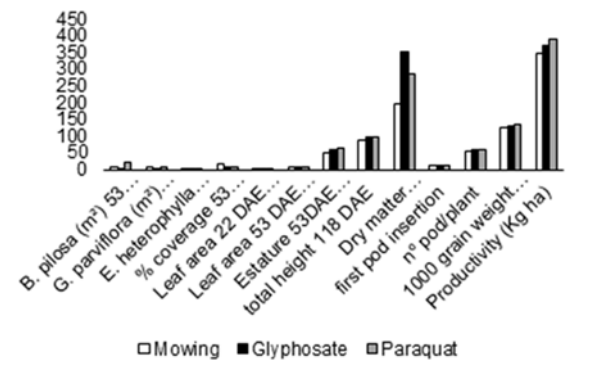


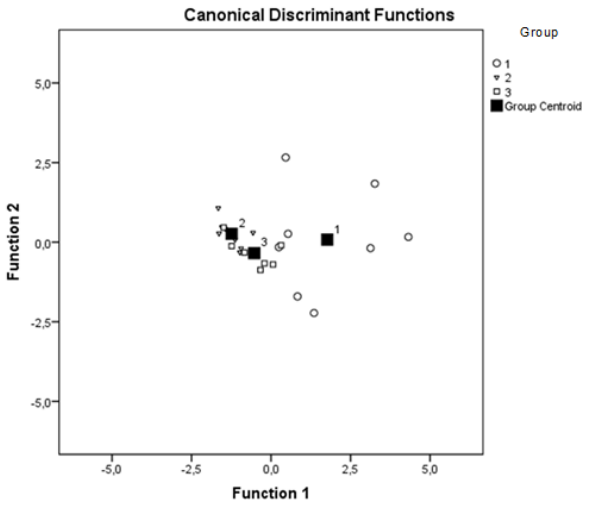
Figure 7 - Evaluation of the efficiency variables among the weed control techniques (mowing, application of glyphosate, and application of paraquat) for the quinoa cover crop. Dois Vizinhos-PR, 2017.

There was a 87.5% correct classification for all weed control techniques used for the soybean crop (mowing and the application of glyphosate application or paraquat, all with the application of post-emergent herbicide). Incorrect classifications only occurred in group 1 (mowing) (3). The centroids of the three control groups were equidistant and separated, indicating that these techniques produce different results for the variables analyzed (Figure 6).

Among the management systems, the application of paraquat provided the highest productivity (kg ha^{-1}) of the soybean crop, whereas glyphosate management proved to be more effective with respect to producing soybean dry matter (kg ha^{-1}) (Figure 7). In both managements, application was post-emergent.

For the fallow area, discriminant analysis selected two soybean productivity variables with discriminatory power, namely, percentage of coverage at 53 DAE of soybean and the number of pods per plant. Two discriminant functions were necessary to classify the management techniques to represent 100% of the variance, with first function contributing 95.4% of the explained variance.

With respect to all management techniques (mowing and application of glyphosate or paraquat, all with application of post-emergent herbicide), there was a 75% correct classification. Six of the classifications were incorrect, one in group 1 (mowing), one in group 2 (glyphosate) and four in group 3 (paraquat). The centroids of the three control groups were equidistant and well separated, indicating that these techniques produced different results in weed control and in the productivity of the soybean crop, although the differences were not notably significant (Figure 8).



Group 1 Mowing; Group 2 Glyphosate; Group 3 Paraquat.

Figure 8 - Classification of assessments of the respective weed control management techniques, with corresponding centroid values, for the fallow area. Dois Vizinhos-PR, 2017.

Management with glyphosate promoted the highest production of dry matter (kg ha^{-1}) in the soybean crop, whereas management with paraquat yielded the highest productivity (kg ha^{-1}). For both these management procedures, the application was post-emergent (Figure 9). Mowing was more efficient in controlling weeds (Figure 5).

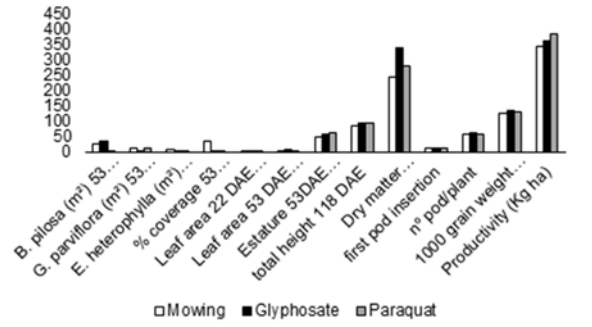


Figure 9 - Evaluation of the efficiency variables among the weed control techniques (mowing, glyphosate and paraquat) for the fallow area. Dois Vizinhos-PR, 2017.

The discriminant analysis identified differences between the management procedures employed according to the type of coverage used. In general, treatment with glyphosate in all cover crops yielded the best results, mainly with respect soybean dry matter production.

Among the cover crops, oats provided the best results, mainly with respect to greater soil coverage, dry mass production, and soybean yield. There were no significant differences among the three management procedures (mowing, glyphosate application and paraquat application), indicating that they had similar effects.

With regards to the chicory cover crop, there was a clear separation of the three management systems. Similarly, for the quinoa cover crop, there were differences among the management systems, with glyphosate and paraquat being similar with respect to most of the variables analyzed.

4 Conclusions

Discriminant analysis identified four variables with discriminatory power, namely, percentage soil cover, soybean height, and the numbers of hairy beggarticks and milkweed plants. The treatment with oats used as a cover crop provided higher soybean crop yield, whereas in terms of management, weed control using glyphosate provided the best results with all cover crops.

5 Contributions

Conceptualization, methodology, investigation, writing, review and editing: AB, PVDM and SJL. Methodology, investigation: PFA and VVB. Writing, review and editing: PR.

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