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Periods of coexistence of weeds with carrot grown with and without black oat straw

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Abstract – The objective of this work was to evaluate the effect of black oat (*Avena strigosa*) straw on the period prior to the interference (PPI) of weeds in the 'Alvorada' carrot (*Daucus carota*) crop. The experiment was carried out in a randomized complete block design, in a 2×5 factorial arrangement, with five replicates. The following two factors were evaluated in the 2016/2017 and 2017/2018 crop years: soil cover, with and without 10 Mg ha^{-1} black oat straw; and periods of coexistence with weeds – 0, 15, 30, 60, and 120 days after emergence (DAE). To determine the PPI, a loss of 5% in the commercial yield of carrot roots was considered as acceptable. At the end of the crop cycle, straw reduced the total dry mass of weeds by 43.5 and 67.5%, respectively, in the first and second crop years. The PPI of the crops with and without straw was, respectively, 2.0 and 1.5 DAE in the first crop year and 17 and 6.0 DAE in the second. The use of black oat straw increases the PPI for the 'Alvorada' carrot crop.

Index terms: *Avena strigosa*, *Daucus carota*, integrated management, no-tillage, weed competition.

Períodos de convivência de plantas daninhas com cenoura cultivada com e sem palhada de aveia-preta

Resumo – O objetivo deste trabalho foi avaliar o efeito da palhada de aveia-preta (*Avena strigosa*) sobre o período anterior à interferência (PAI) de plantas daninhas na cultura da cenoura 'Alvorada' (*Daucus carota*). O experimento foi realizado em delineamento de blocos ao acaso, em arranjo fatorial 2×5, com cinco repetições. Os dois seguintes fatores foram avaliados nos anos de cultivo de 2016/2017 e 2017/2018: cobertura de solo com e sem 10 Mg ha^{-1} de palhada de aveia-preta; e períodos de coexistência com as plantas daninhas – 0, 15, 30, 60 e 120 dias após a emergência (DAE). Para determinar o PAI, considerou-se como aceitável a perda de 5% na produtividade comercial de raízes da cenoura. Ao final do ciclo da cultura, a palhada reduziu a massa seca total de plantas daninhas em 43,5 e 67,5%, respectivamente, no primeiro e no segundo ano de cultivo. O PAI dos cultivos com e sem palhada foi, respectivamente, de 2,0 e 1,5 DAE no primeiro ano e de 17 e 6,0 DAE no segundo. O uso da palhada de aveia-preta aumenta o PAI para cultura da cenoura 'Alvorada'.

Termos para indexação: *Avena strigosa*, *Daucus carota*, manejo integrado, plantio direto, matocompetição.

Introduction

Carrot (*Daucus carota* L.) stands out among the main vegetables produced and consumed in Brazil and worldwide (Canella et al., 2018; FAO, 2020). In Brazil, carrots can be grown throughout the year when the specific cultivar for autumn-winter, spring, or summer is chosen (Resende et al., 2005).

Carrot root yield may range from 20 to 100 Mg ha^{-1} depending on the used production system (conventional or organic), irrigation, sowing density and spacing, sowing and harvesting time, and cultivated species (Carvalho et al., 2020). However, despite this high yield potential, weed interference may reduce total root yield by up to 96% (Freitas et al., 2009), besides stimulating the deformation of developing roots, decreasing their quality and hindering mechanical harvesting (Soares et al., 2010). Therefore, weed control measures need to be adopted (Reginaldo et al., 2021).

Herbicide use is the main method for weed control in the carrot crop (de Boer et al., 2019). However, with the increasing public concern about the use of chemicals in agricultural production, research efforts have intensified to reduce the amount of herbicides applied in carrot production (Main et al., 2013). The use of grass straw as mulch is an economically viable alternative for weed control (Hirata et al., 2019), mainly in organic crops (Bernstein et al., 2014).

Black oat (*Avena strigosa* Schreb.) forage has a high biomass production potential of 12 Mg ha^{-1} (Demétrio et al., 2012) and its straw can be used in the integrated management of weeds, besides producing allelopathic compounds (Sturm et al., 2016). However, more information is needed on the use of straw for the suppression of the seed bank in the carrot crop.

Despite this, soil cover can confer competitive advantage to carrot plants by slowing their initial growth and significantly increasing leaf dry mass accumulation starting only at 30 days after seedling emergence (Colquhoun et al., 2017). This period coincides with the beginning of the critical period for weed control in crops cultivated without soil cover (Coelho et al., 2009). Therefore, it is important to evaluate if the use of black oat straw can increase the tolerance of the carrot crop to weeds by suppressing the emergence of the seed bank and, consequently, reduce the need for control measures.

The objective of this work was to evaluate the effect of black oat straw on the period prior to the interference (PPI) of weeds in the 'Alvorada' carrot crop.

Materials and Methods

The experiment was conducted from October to February of the 2016/2017 and 2017/2018 crop years in the municipality of Ponta Grossa, in the state of Paraná, Brazil (25°13'S, 50°03'W, at an average altitude of 880 m). The climatic data throughout the experimental period are presented in Figure 1.

Before the experiment was implemented in the first crop year, the soil of the experimental area was subjected to chemical analysis and presented the following characteristics: pH ($CaCl_2$) 5.2, 6.2 $cmol_c$ dm^{-3} H+Al, 0 $cmol_c$ dm^{-3} Al, 5.5 $cmol_c$ dm^{-3} Ca, 2.4 $cmol_c$ dm^{-3} Mg, 0.56 $cmol_c$ dm^{-3} K, 25 mg dm^{-3} P, 9.6 mg dm^{-3} SO_4, 31 g dm^{-3} organic C, cation exchange capacity at pH 7.0 of 14.67 $cmol_c$ dm^{-3}, and base saturation of 58%.

The experimental design was a randomized complete block in a 2×5 factorial arrangement, with five replicates. The two evaluated factors were: soil cover, with and without black oat straw; and periods of coexistence of the carrot crop with weeds in days – 0, 15, 30, 60, and 120 days after emergence (DAE).

Five days before sowing, 500 kg ha^{-1} N-P_2O_5-K_2O (04-14-08) were incorporated into the soil and, 30 days after sowing, 50 and 80 kg ha^{-1} potassium chloride and urea were applied as topdressing, respectively, according to the recommendation of Raij et al. (1997).

The soil was gridded, and 1.0 m wide and 40 m long beds were raised mechanically. Each experimental unit consisted of a 2.0 m long and 1.0 m wide bed with five lines. Shortly after the preparation of the beds, black oat straw was deposited manually in the plots with mulch in order to obtain 10 Mg ha^{-1} of cover, i.e., 1.0 kg m^{-2}. The straw deposited on the beds was obtained from 'Embrapa 139' black oat plants, which were previously cultivated each year in an area close to the experiment and then cut in the flowering stage and dried in the field.

In each crop year, seeds of the 'Alvorada' carrot were sown in October. Thinning was performed 30 days after sowing, keeping ten plants per meter, with a spacing of 0.10 m between plants and 0.20 m between rows. Both sowing and weeding were done manually.

At the end of each period of coexistence (0, 15, 30, 60, and 120 DAE) and before weeding, a metallic 50×50 cm frame was cast twice in the center of each plot, from where weeds were collected. The relative importance index (RII%) of the species present in the weed community in each coexistence period was then determined according to Mueller-Dombois & Ellemberg (1974) and by the similarity index (SI) of Sørensen (1948) between crop years, using the formula: SI = [(2c/a+b) x 100], where c is the number of species common to the two areas, a is the total number of species present in the area in the first crop year, and b is the total number of species present in the area in the second crop year.

The collected weeds were identified, quantified, and dried in a greenhouse under forced-air circulation, at 60°C, until reaching constant dry mass, and then weighed on a precision scale (0.001 g) to obtain the total dry mass of weeds in each period, which was extrapolated to Mg ha^{-1}.

At the time of harvest – February 2017 and 2018 in the first and second crop years, respectively –, carrot plants were manually collected in a 0.3 m^2 area observing the standard size for marketable roots, which is of at least 10 cm. The total yield (Mg ha^{-1}) of the marketable roots was obtained for each plot.

To determine the periods prior to the interference (PPI) of weeds, the yield data of marketable roots was used, considering as a criterion a 5% yield loss as acceptable (Coelho et al., 2009; Freitas et al., 2009).

Data on the accumulation of total dry weed mass and on the yield of marketable carrot roots were subjected to the joint analysis of variance. Means were adjusted to regression models, and the used equations were chosen based on significant models (p≤0.05), normality, high coefficient of determination, and biological logic.

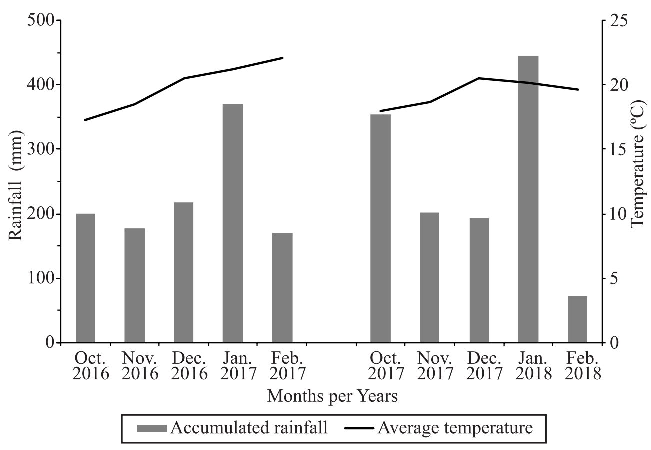

Figure 1. Climatic data during the experimental period from October to February 2016/2017 and 2017/2018 in the municipality of Ponta Grossa, in the state of Paraná, Brazil. Data obtained from the climatological station of Fazenda Escola Capão da Onça, also located in the state of Paraná.

Results and Discussion

In the treatments with and without straw in the two crop years, ten weed species were identified, being distributed in the seven following families: Asteraceae family, *Bidens pilosa* L., *Conyza bonariensis* (L.) Cronquist, and *Galinsoga ciliata* S.F.Blake; Brassicaceae, *Raphanus* sp.; Cyperaceae, *Cyperus rotundus* L.; Euphorbiaceae, *Euphorbia heterophylla* L.; Oxalidaceae, *Oxalis latifolia* Kunth; Plantaginaceae, *Plantago tomentosa* Cham. & Schltdl.; and Poaceae, *Brachiaria mutica* Stapf and *Eragrostis pilosa* (L.) P.Beauv.

In both crop years, the floristic composition of the weed community in the carrot crops with and without straw showed a high similarity of 100%. However, the *B. mutica*, *E. heterophylla*, *E. pilosa*, and *G. ciliata* species had the greatest competitive effect due to their highest RII% values in practically all coexistence periods in 2016/2017 and 2017/2018 (Figure 2). This high similarity between the weed species can be explained by the fact that the experiment was carried out in the same location and, therefore, the identified species belong to the same community, showing similar density, frequency, and abundance indices.

The use of black oat straw negatively influenced the emergence and development of weed species, significantly reducing biomass accumulation in both crop years (Table 1 and Figure 3). The increases in weed dry mass accumulation intensified at 15 DAE when straw was not used, but only at 30 DAE when it was (Figure 3). In addition to slowing weed growth, the use of straw reduced the maximum biomass accumulation by around 43.4 and 55.7% in 2016/2017 and 2017/2018, respectively.

Silva et al. (2013) also found a reduction of 87.3% in the accumulation of weed dry mass when using *Urochloa brizantha* (A.Rich.) R.D.Webster as a cover plant in watermelon [*Citrullus lanatus* (Thunb.) Mansf.] crops. Moreover, according to these authors, the need of weeding/tillage was reduced in the areas with straw in comparison with those without it. Hirata et al. (2019) reported that *Urochloa decumbens* (Stapf) R.D.Webster straw reduced the density of the weed community by 98.6%, standing out as an effective tool in the integrated management of weeds during cauliflower (*Brassica oleracea* var. *botrytis* L.) cultivation, without interfering in crop yield.

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Favarato et al. (2014) observed a reduction of up to 91.8% in the absolute density of weeds when using the straw of black oat alone or combined with white lupine (*Lupinus albus* L.) as soil cover for a green corn (*Zea mays* L.) crop grown in an organic no-tillage system. Likewise, in the broccoli (*Brassica oleracea* L. var. *italica* Plenck) crop, the use of black oat straw reduced weed density by up to 43% (Frutos et al., 2016). Besides functioning as a barrier to the passage of light and the emergence of the soil seed bank, black oat straw has a strong allelopathic inhibitor effect on some weed species (Rueda-Ayala et al., 2015), inhibiting, for

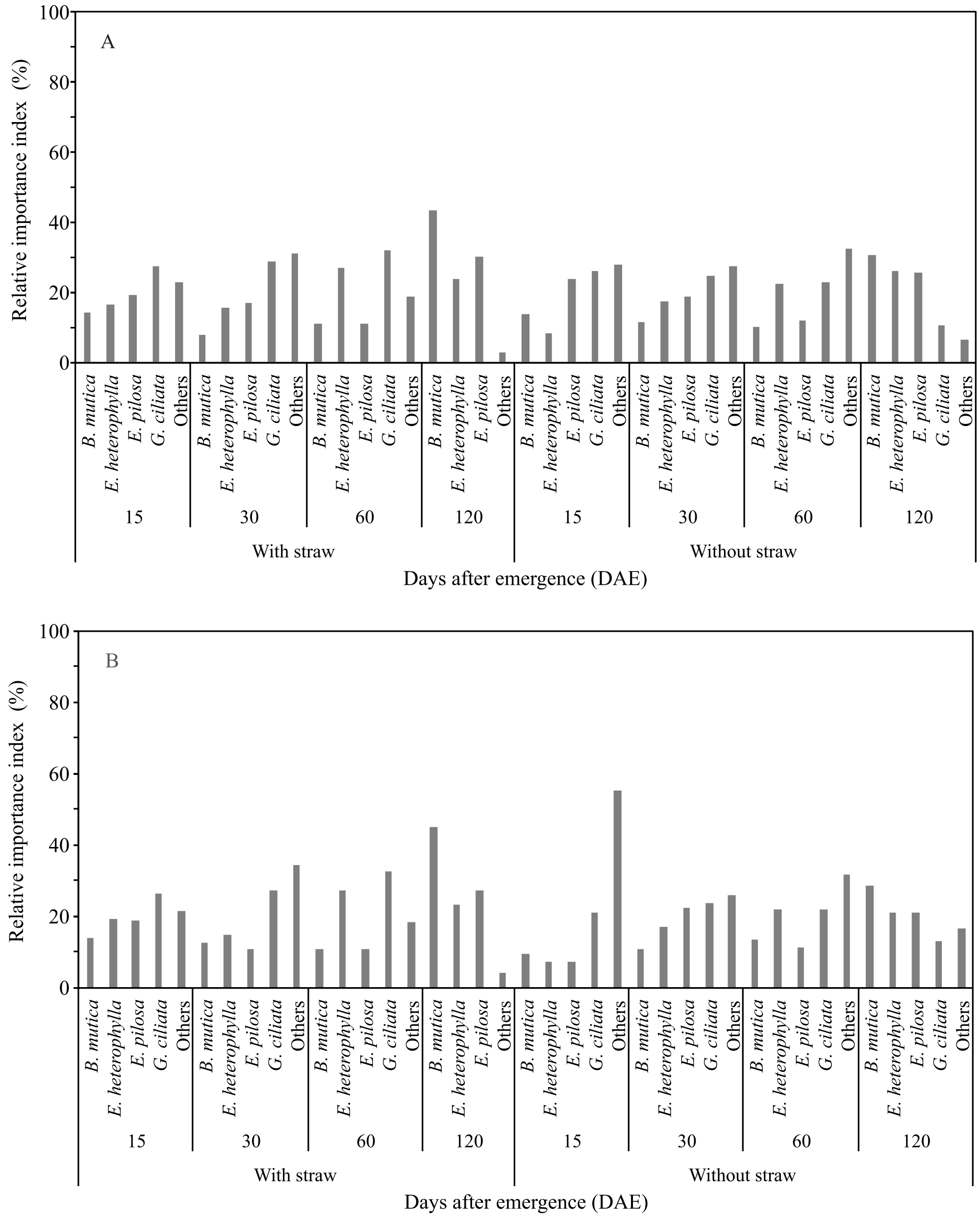

Figure 2. Relative importance index of the weed community in different coexistence periods – 0, 15, 30, 60 and 120 days after emergence – with the 'Alvorada' carrot (*Daucus carota*) crop cultivated with and without black oat (*Avena strigosa*) straw in the 2016/2017 (A) and 2017/2018 (B) crop years. Main identified weeds: *Brachiaria mutica*, *Euphorbia heterophylla*, *Bidens pilosa*, and *Galinsoga ciliata*.

example, the germination and growth of *Euphorbia heterophylla* L. (Hagemann et al., 2010), one of the main species identified in the present study.

In general, the commercial yield of carrot roots was extremely sensitive to the coexisting weed community, mainly when cultivated without black oat straw (Table 2 and Figure 4). However, in both crop years, the coexistence of weeds throughout the carrot cycle hindered the commercial production of roots.

The results of the present study are similar to those of Freitas et al. (2009) and Soares et al. (2010), who observed losses of up to 91% in carrot root yield in

Table 1. Summary of the joint analysis of variance of the dry mass accumulation data of weeds during the period of coexistence – 0, 15, 30, 60, 120 days after emergence – with the 'Alvorada' carrot (*Daucus carota*) crop cultivated with and without black oat straw (*Avena strigosa*).

Variation factor	Degree of freedom	Mean square
Block (year)	6	0.02^{ns}
Year (A)	1	34.98**
Mulch (M)	1	28.62**
Period (P)	4	34.35**
A × M	1	1.91**
A × P	4	7.20**
M × P	4	3.43**
A × P × M	4	0.34*
Error	54	0.10
CV (%)		19.93

** and *Significant by the F-test at 1 and 5% probability, respectively. ^{ns}Nonsignificant.

Table 2. Summary of the joint analysis of variance of the yield data of commercial roots of the 'Alvorada' carrot (*Daucus carota*) crop cultivated with and without black oat (*Avena strigosa*) straw and subjected to periods of coexistence with weeds (0, 15, 30, 60, 120 days after emergence).

Variation factor	Degree of freedom	Mean square
Block (year)	6	0.84^{ns}
Year (A)	1	1,464.02**
Mulch (M)	1	2,793.66**
Periods (P)	4	10,217.97**
A × M	1	65.29**
A × P	4	311.89**
M × P	4	337.35**
A × P × M	4	34.09**
Error	54	2.01
CV (%)		4.32

** and *Significant by the F-test at 1 and 5% probability, respectively. ^{ns}Nonsignificant.

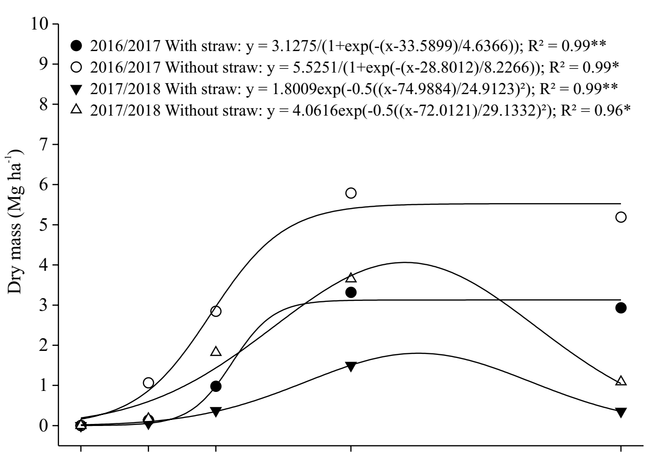

Figure 3. Accumulation of weed dry mass as a function of the period of coexistence with the 'Alvorada' carrot (*Daucus carota*) crop, cultivated with and without black oat (*Avena strigosa*) straw, in the 2016/2017 and 2017/2018 crop years. ** and *Significant by the F-test, at 1 and 5% probability, respectively.

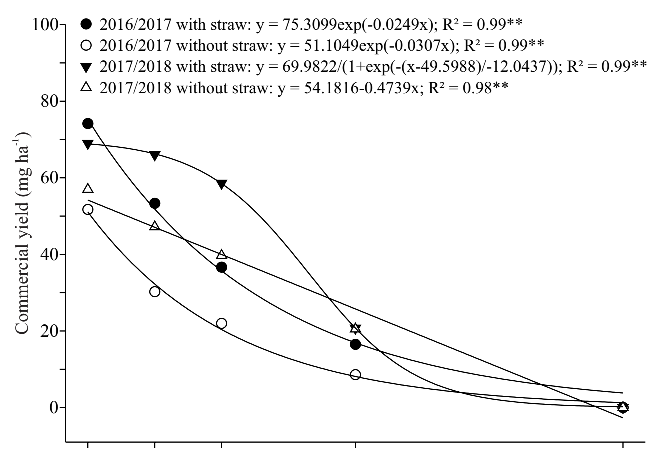

Figure 4. Commercial yield of 'Alvorada' carrot (*Daucus carota*) roots as a function of the period of coexistence with weeds when cultivated with and without black oat (*Avena strigosa*) straw in the 2016/2017 and 2017/2018 crop years. **Significant by the F-test, at 1% probability.

the absence of weed control. However, considering the commercial yield of the roots obtained in the plots without weed coexistence, a 32.1 and 22.5% higher yield was found in the crops with black oat straw in the first and second crop years, respectively. Using different types of cover crops, Resende et al. (2005) and Santos et al. (2011) also reported an increased carrot crop yield of, in average, 32 and 13%, respectively. In other crops, such as lettuce (*Lactuca sativa* L.) and strawberry [*Fragaria* × *ananassa* (Weston) Duchesne ex Rozier], the use of soil cover provided gains of 32 and 2.5% in commercial yield, respectively (Barbosa et al., 2018; Tonin et al., 2017).

Other benefits of straw include protecting the soil against erosive or degradation factors, as well as favoring the development of microorganisms that aid in nutrient cycling after the decomposition of plant material (Gatiboni et al., 2011). The release of nutrients and organic compounds combined with the maintenance of moisture promoted by straw cover on the soil forms an environment favorable for the development of crop roots, consequently promoting increases in nutrient absorption rate and yield (Brito et al., 2017; Lowry & Brainard, 2019).

Considering as acceptable a yield loss of 5% for 'Alvorada' carrot, the PPI obtained with and without black oat straw was of 2.0 and 1.5 DAE, respectively, in 2016/2017 and of 17 and 6 DAE in 2017/2018. This difference in PPI values with and without straw can be attributed to soil disturbance while the beds were being prepared, altering the distribution of weed seeds in the soil layers, which can alter emergence dynamics and the interaction with straw cover.

Freitas et al. (2009) found a PPI of 19 and 18 DAE for 'Brasília' carrot sown without straw with a spacing of 15×6 and 20×6 cm between rows, respectively, in the municipality of Mossoró, in the state of Rio Grande do Norte, Brazil. For the same crop, Coelho et al. (2009) reported a PPI of 31 days after sowing in lines spaced at 20 cm, in the municipality of Anápolis, in the state of Goiás, also Brazil. These values are higher than those obtained in the present study probably due to differences in the tolerance of the used varieties to weed competition, differences in the edaphoclimatic characteristics of each study region, the adopted production system, and the weed community present in the experimental areas.

Considering mainly the data of the 2017/2018 crop year, the results of the present study are indicative that the carrot plants cultivated with black oat straw as soil cover were able to coexist with weeds in the early growth stages for up to 11 days more than those that were not. Therefore, the use of black oat straw in carrot crops for integrated weed management can improve crop yield potential.

Conclusion

The use of black oat (*Avena strigosa*) straw increases the period prior to the interference of weeds in the 'Alvorada' carrot crop.

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