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Interference and level of economic damage of turnip in canola. Interferência e nível de dano econômico do nabo em canola.

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Abstract

The weeds if not properly controlled have great ability to settle in agricultural systems, affecting crop production. The objective of this work was to determine the interference and level of economic damage in different density of crop. The treatments were composed of canola hybrids (Hyola 50, Hyola 76, Hyola 433, Hyola 571 CL, Hyola 575 CL and Diamond) and twelve infestation turnip density in crop. The variables evaluated to estimate the competitiveness of the hybrids were plant density, leaf area, soil cover and dry mass of the turnip. Grain yield, canola price, herbicide efficiency, and control cost were used to determine the weed's level of economic damage on the crop. The canola hybrids Hyola 575 CL, Hyola 50, Hyola 76 and Hyola 571 CL are more competitive with turnip. The values of economic damage levels range from 2.86 to 5.95, 2.43 to 5.05, 2.22 to 5.43 and 2.99 to 6.22 turnip plants m^{-2} for hybrids Hyola 50, Hyola 76, Hyola 571 CL and Hyola 575 CL, respectively, as a function of simulated variables. The increased grain yield, canola price, herbicide efficiency and lower control costs reduce the level of economic damage, justifying the adoption of control.
Keywords: *Brassica napus* var. oleifera. Competition of plants. *Raphanus raphanistrum*.

Resumo

As plantas daninhas, se não forem devidamente controladas, têm grande capacidade de se instalarem nos sistemas agrícolas, afetando a produção de culturas. O objetivo deste trabalho foi determinar a interferência e o nível de danos econômicos em diferentes densidades de cultura. Os tratamentos foram compostos por híbridos de canola (Hyola 50, Hyola 76, Hyola 433, Hyola 571 CL, Hyola 575 CL e Diamond) e doze infestação de densidade de nabos na cultura. As variáveis avaliadas para estimar a competitividade dos híbridos foram densidade de plantas, área foliar, cobertura do solo e massa seca do nabo. O rendimento dos grãos, o preço da canola, a eficiência dos herbicidas e o custo de controles foram utilizados para determinar o nível de danos econômicos da cultura de plantas daninhas. Os híbridos de canola Hyola 575 CL, Hyola 50, Hyola 76 e Hyola 571 CL são mais competitivos com o nabo. Os valores dos níveis de danos econômicos variam de 2,86 a 5,95, 2,43 a 5,05, 2,22 a 5,43 e 2,99 a 6,22 nabiças m^{-2} para os híbridos Hyola 50, Hyola 76, Hyola 571 CL e Hyola 575 CL, respectivamente, em função de variáveis simuladas. O aumento do rendimento dos grãos, o preço da canola, a eficiência dos herbicidas e os custos de controles mais baixos reduzem o nível de prejuízos econômicos, justificando a adoção do controle.
Palavras-chave: *Brassica napus* var. oleífera. Competição de plantas. *Raphanus raphanistrum*.

Introduction

Brazil produced 49.5 thousand tons of canola (*Brassica napus* L. variety oleifera) in the 2017/18 harvest (CONAB, 2020). Besides being one of the most produced oil plants in the world, it represents an excellent potential for grain production in Brazil (KIRKEGAARD et al., 2018).

As a result of the high production of edible oils, biofuels and also feed bran, canola is an economic alternative (TOMM et al., 2009). In addition to integrating different grain production systems that can be used in crop rotation, it also helps to reduce phytosanitary problems occurring in grasses, legumes and other crops (TOMM et al., 2009).

With the increase in demand for canola cultivation in Brazil, the research is seeking to adapt the forms of management in order to increase yields and the more sustainable production of crops (TOMM et al., 2009). Even with increasing research, there is still insufficient information related to the challenges of canola cultivation. It is known that practices aimed at the integrated management of weeds, including the use of competitive hybrids, are necessary to sustain the production of oleaginous crops (BECKIE et al., 2008 ; LEMERLE et al., 2017).

Weeds are one of the main factors that reduce the productivity of agricultural crops, including canola, and, when not managed, they cause high losses in productivity and the quality of the grains produced. The competition of weeds can cause a change in the use of medium resources (water, light and nutrients). Weeds are more aggressive, adaptable and persistent than crops and therefore pose a serious threat to agricultural production due to the ability to survive under adverse conditions, extracting more water and nutrients from the soil and thus reducing crop yields (KAUR et al., 2018).

It is known that there are few herbicides registered for canola, mainly selective for the crop when applied in post-emergence, which generates greater difficulty in weed control (VARGAS et al., 2011). In order to achieve weed suppression through cultivated plant manipulations, multiple tactics must be improved and combined, which will result in benefits to the crop, such as a reduction in the need for herbicide application, which also results in reduced environmental impact associated with the uncontrolled use of herbicide (LOWRY, SMITH, 2018).

Among the major weeds that infest the winter crops in southern Brazil, it is worth mentioning ryegrass (*Lolium multiflorum*) and turnip (*Raphanus raphanistrum*) (TIRONI et al., 2014). Turnip is the weed that causes the most problems in canola culture, as it belongs to the same family (GALON et al., 2015). The most important and most competitive weeds in a crop are those that belong to the same botanical family of the crop because they present similar needs for resources and also explore the same niche as the crop (AGOSTINETTO et al., 2010).

There have been few works carried out for the management of weeds occurring in canola, in particular those focused on determining the level of economic damage (EDL) of these plants when infesting the crop.

The EDL serves as a basis for decision-making for weed control; without it, there can be difficulties with handling the crop, in addition to a lower efficiency with the use of herbicides, increasing production costs, and increased environmental effects related to the excessive use of herbicides (GALON et al., 2007).

It is known that the population of cultivated plants is usually constant, since the population of weeds may vary according to the seed bank present in the soil, as well as with the environmental conditions that may change the level of infestation (AGOSTINETTO et al., 2010; GALON et al., 2019).

The competitive capacity of a crop can be specified by tolerating weed infestation or by inhibiting weed growth due to resource competition (BERTHOLDSSON, 2010). Generally, the most competitive cultivars, that is, those which present greater vigor, increased growth and a higher index of leaf area, have a greater capacity to compete for light, nutrients and water in relation to the other cultivars that express fewer of these characteristics. Also, characteristics such as plant canopy architecture, stature, and dry mass, among other characteristics that are expressed by the crop, tend to suppress the growth, development and reproduction of nearby weed species (WORTHINGTON et al., 2015).

In competition studies it is not only possible to evaluate the population of plants that exist in the competitive process, but it is also important to verify the influence of the oscillation that occurs in the ratio between the species, since the density of weeds is the most damaging factor interfering with crops of agronomic interest (GALON et al., 2014).

The hypothesis of the current work is that there is differentiation in the competitive ability and level of economic damage according to the cultivation of different canola hybrids (Hyola 50, Hyola 76, Hyola 433, Hyola 571 CL, Hyola 575 CL and Diamond) in coexistence with populations.

In view of the above, the objective of this work was to determine the interference and level of economic damage of canola hybrids.

Materials and methods

Description of the experimental site

The experiment was carried out in the experimental area of the Federal University of Fronteira Sul (UFFS), Erechim/RS, in the agricultural year 2017, and the soil was classified as Red Latosol (EMBRAPA, 2013). The climate of the location is of the type Cfa (humid temperate climate with hot summer) according to the classification established by Koeppen, in which the rains are well distributed throughout the year (CEMET-RS, 2012). PH correction and soil fertilization were performed according to physicochemical analysis and following the technical recommendations for canola cultivation (ROLAS, 2016).

Preparing the area for sowing

Before sowing the canola, the area was burned down area with the glyphosate herbicide (1080 g ha^{-1} acid equivalent). Each experimental unit (plot) was composed of an area of 15.0 m^2 (3.0 x 5.0 m), sown in 6 rows, with a spacing of 0.50 m between and 5 m along. The sowing density of the canola hybrids was 50 plants m^{-2} or approximately 2.0 kg ha^{-1} seeds.

Treatments used

The experimental design was a randomized complete block, four repetition. Hyola 50 (average cycle and height 118-150 cm), Hyola 76 (long cycle and height 126-159 cm), Hyola 50433 (short cycle and height 124-131 cm), Hyola 571 CL (medium cycle and height 83-178 cm), Hyola 575 CL (short cycle and height 116-144 cm) and Diamond (short cycle and height 100-110 cm), as well as turnip populations (0, 8, 12, 44, 80, 144, 164, 192, 220, 720, 824 and 868, 0, 12, 24, 28, 60, 104, 200, 292 , 352, 808, 820 and 908, 0, 4, 5, 10, 11, 12, 31, 80, 104, 185, 215 and 376, 0, 16, 20, 28, 56, 140, 148, 164, 204, 440, 832 and 848, 0, 8, 16, 52, 64, 152, 156, 408, 476, 1028, 1300 and 1696 and 0, 4, 16, 28, 32, 88, 206, 568, 648, 1248 and 1600 plants m^{-2}), in competition with the respective canola hybrids. Turnip plants were sown and the establishment of populations was varied, since factors such as infestation, vigor, and humidity, among others, prevent the establishment of exactly the same number of plants per area (experimental unit).

When the canola was in the B3 stage (three true leaves unrolled) nitrogen was applied in a 150 kg ha^{-1} cover, in the form of urea, according to the soil chemical analysis and crop yield expectation. All other management practices used were those recommended by the research for the canola crop (TOMM et al., 2009).

Variables and methods used for evaluation

Plant population (PP), soil cover (CS), leaf area (AF) or dry mass of the turnip (MSPA) were performed at 51 days after emergence (DAE) of the crop. To determine the PP variable, plant counts were performed in two areas of 0.25 m^2 (0.5 m x 0.5 m) per plot. The CS by turnip plants was evaluated visually, individually by two evaluators, using a percentage scale, in which the zero mark corresponds to the absence of CS and the 100 mark represents total soil cover. The FA quantification of the competing plant was performed with a portable AF electronic integrator, model CI-203, brand CID Bio-Science, measuring all plants in an area of 0.25 m^2 per plot. The MSPA of turnip plants (g m^{-2}) was determined by collecting the plants contained in an area of 0.25 m^2 per plot and dried in a forced circulation oven at 60 ±5ºC until reaching a constant mass.

Mathematical analysis of interference and economic damage level

The quantification of the yield of canola grains was obtained by harvesting the plants in a useful area of 4.5 m^2 of each experimental unit, when the grain moisture content reached approximately 18%. After weighing the grains, their moisture was determined and, later, the masses were standardized to 13% moisture. With the grain yield data, the percentage losses were calculated in relation to the plots maintained without infestation (controls), according to Equation 1:

$$Loss\ (\%) = \left(\frac{Ra - Rb}{Ra}\right)x100 \qquad \text{Equation 1}$$

Where Ra and Rb denote the yield of the crop without or with presence of the competing plant, turnip, respectively. Before the analysis of the data, the values of CS (%), AF (cm^2) and MS (g m^{-2}) were multiplied by 100, thus dispensing with the correction factor in the model (GALON et al., 2007; AGOSTINETTO et al., 2010).

The relationships between percentage losses of canola productivity as a function of the explanatory variables were calculated separately for each hybrid, using the nonlinear regression model derived from the rectangular hyperbola, proposed by Cousens in 1985, according to Equation 2, in which it was used to calculate productivity losses:

$$Pp = \frac{(i.x)}{(1 + (\frac{i}{a}).x)} \qquad \text{Equation 2}$$

Where: Pp = loss of productivity (%); X = turnip population, soil cover, leaf area and dry mass of shoot; i and a = productivity losses (%) per unit of turnip plants when the value of the variable approaches zero and when it tends to infinity, respectively. For the calculation procedure, the Gauss-Newton method was used, which, by successive iterations, estimates the values of the parameters, in which the sum of the squares of the deviations of the observations in relation to the adjusted values is minimal. The value of the F statistic ($p \leq 0.05$) was used as the criterion for analyzing the data in the model. The criterion of acceptance of the fit of the data to the model was based on the higher value of the coefficient of determination (R^2) and lower value of the mean square of the residue (QMR).

In order to calculate the economic damage level (EDL), we used the estimates of parameter i obtained from Equation 2 (COUSENS, 1985) and the Equation adapted from Lindquist and Kropff (1996) in Equation 3:

$$EDL = \frac{(cc)}{(R.P.(\frac{i}{100}).(\frac{H}{100}))} \qquad \text{Equation 3}$$

Where EDL = economic damage level (m^2 plants), *Cc* = cost of control (herbicide and tratorized land application, in dollars ha^{-1}), R = yield of canola grains (kg ha^{-1}), P = price of canola (kg^{-1} of grains), i = loss (%) of canola productivity per competing plant unit when the population level approaches zero, and H = herbicide efficiency (%). The application of the herbicide imazamox-Raptor® (42 g ha^{-1}) + mineral oil - Dash® (0.5% v/v) was used to simulate the data, since it was registered for the control of turnip in hybrids of product Clearfield® canola.

For the variables *Cc*, *R*, *P* and *H* (Equation 3), three values occurring in the last 10 years were estimated. Thus, for the control cost (*Cc*), the average price was considered, with the maximum and minimum cost being changed by 25%, in relation to the average cost. The productivity of canola (*R*) was based on the lowest, medium and highest values obtained in Rio Grande do Sul, in the last 10 years. The price of the product (*P*) was estimated from the lowest, middle and highest price of canola per 60 kg bag in the last 10 years. The values for the herbicide (*H*) efficiency were established in the order of 80, 90 and 100% control, with 80% being considered the minimum effective control of the weed (SBCPD, 1995). For the EDL simulations, the intermediate values were used for the variables that were not being calculated.

Results and discussion

Evidence of fit of data to the rectangular hyperbole model

The explanatory variables plant population (PP), leaf area (FA), soil cover (CS) and shoot dry mass (MSPA) of turnip for all evaluated canola hybrids presented significant F statistic values (Fig. 1, 2, 3 or 4). The results show that the PP, AF, CS and MS variables for the canola hybrids Hyola 50, Hyola 76, Hyola 433, Hyola 571 CL, Hyola 575 CL and Diamond conform to the appropriate rectangular hyperbole model, where the data presented values of R^2 higher than 0.62 and low mean square of the residue (QMR), which characterizes good fit of the data to the model. According to Cargnelutti Filho and Storck (2007), when working with genetic variation, cultivar effect and the heritability of maize hybrids, they considered R^2 values between 0.57 and 0.66 to be good, which corroborates, in part, the results found in the present study.

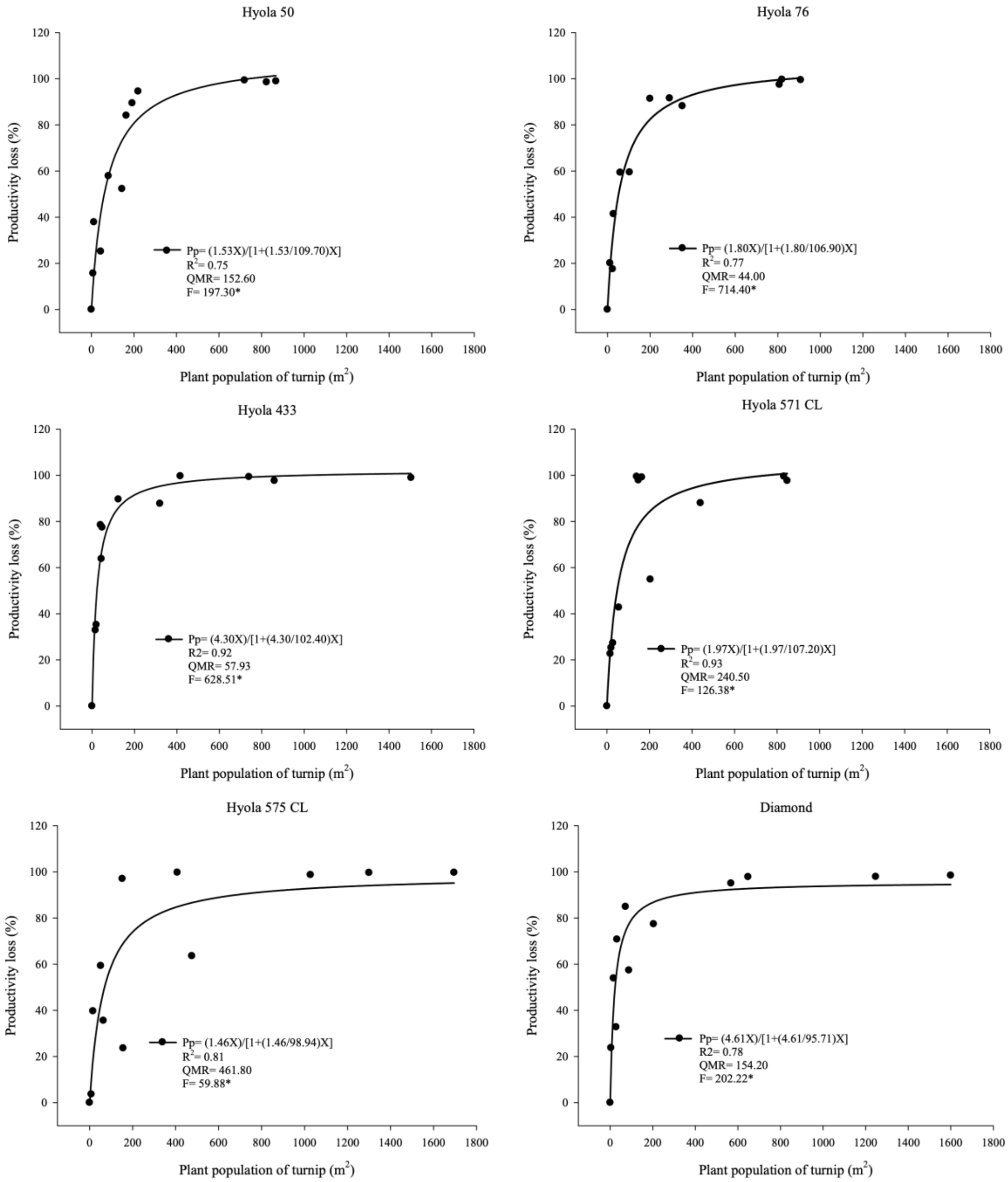

Fig. 1 - Loss of productivity (Pp) of canola hybrids as a function of population of plants m^{-2} turnip at 51 days after emergence. UFFS, Erechim/RS, 2018. R^2 = Coefficient of determination; QMR: mean square of residue; * Significant at $p \leq 0.05$.

Determination of the competitive ability of canola and turnip hybrids

The estimated values for parameter *i* tended to be lower for PP, AF, CS and MS variables for Hyola 50 (medium cycle), Hyola 76 (long cycle), Hyola 571 CL or Hyola 575 CL (short cycle) (Fig. 1, 2, 3 or 4). On the other hand, the smaller competitions were observed in the hybrids Hyola 433 and Diamond, possibly due to its cycle being shorter, favoring a faster development and having a smaller stature, which allowed the greater passage of radiation and consequent new flow of emergence of turnip plants, after determining the explanatory variables (51 DAE). According to Galon al. (2007) rice cultivars with low soil cover allow greater penetration of light in the community canopy and consequently less competition with weeds.

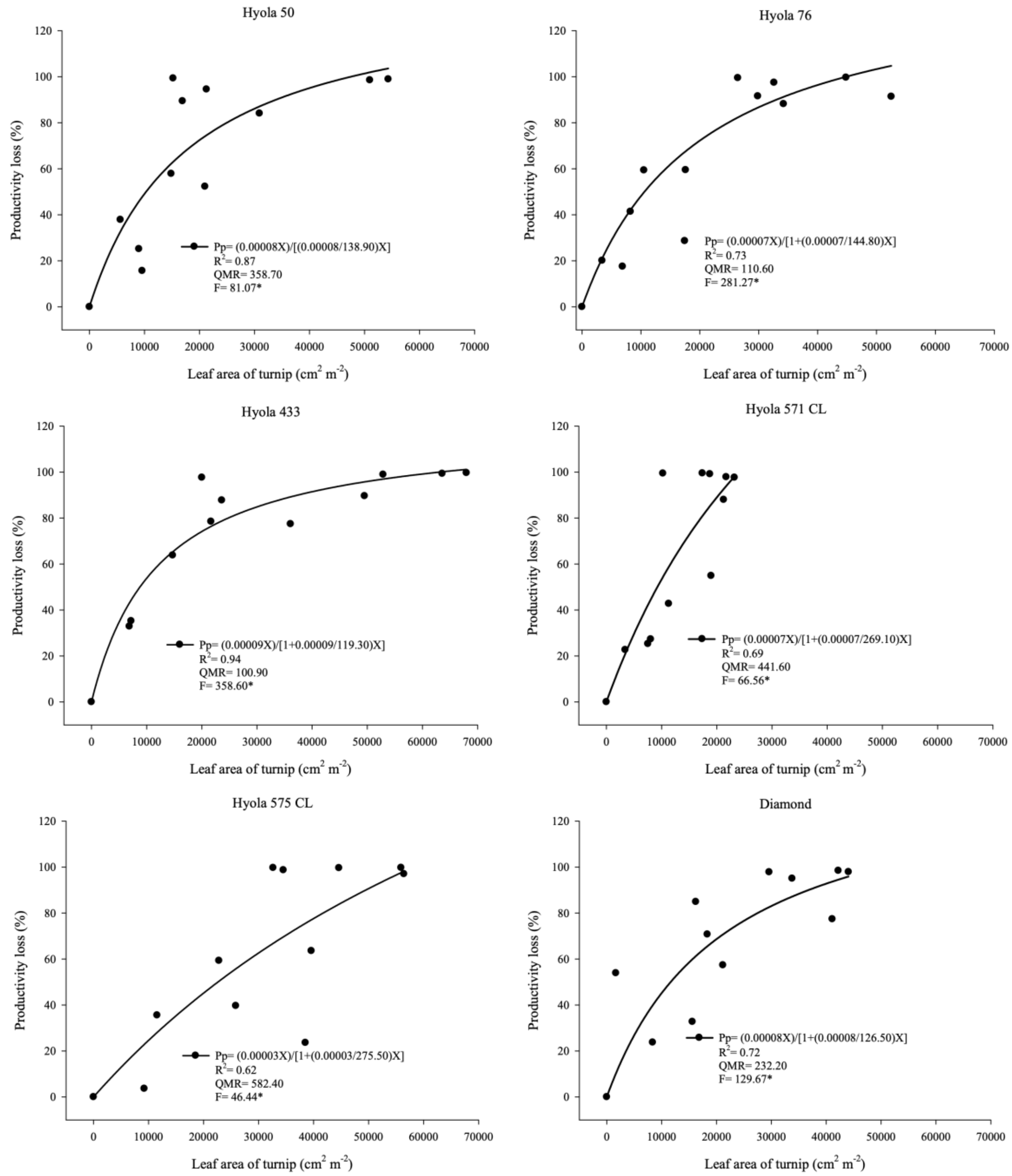

Fig. 2 - Loss of productivity (Pp) of canola hybrids as a function of leaf area (cm^2 m^{-2}) of turnip at 51 days after emergence. UFFS, Erechim/RS, 2018. R^2 = Coefficient of determination; QMR: mean square of residue; * Significant at $p \leq 0.05$.

The differentiated competitive ability among cultivars of a cultivated species is a common feature, as observed for rice cultivars (GALON et al., 2007). In addition, some management practices, such as sowing density, may influence the competitive ability of cultivars (AGOSTINETTO et al., 2010).

Several researches report differentiated responses of parameter *i* when working with different cultivars of the crop, soybean (BIANCHI et al., 2006), rice (AGOSTINETTO et al., 2010), wheat (GALON et al., 2019), and common bean (KALSING, VIDAL, 2013) when infested by weed populations.

Since parameter *i* is an index used to compare the relative competitiveness between species (SWINTON et al., 1994), differentiated values for the canola hybrids were found in the explanatory variables tested (Fig. 1, 2, 3 or 4). The comparison between the hybrids considering parameter *i*, in the average of the four explanatory variables (PP, MSPA, CS or AF), showed that the placement order in relation to the competitiveness of the arrangements between plants was: Hyola 575 CL > Hyola 50 > Hyola 76 > Hyola 571 CL > Hyola 433 > Diamond.

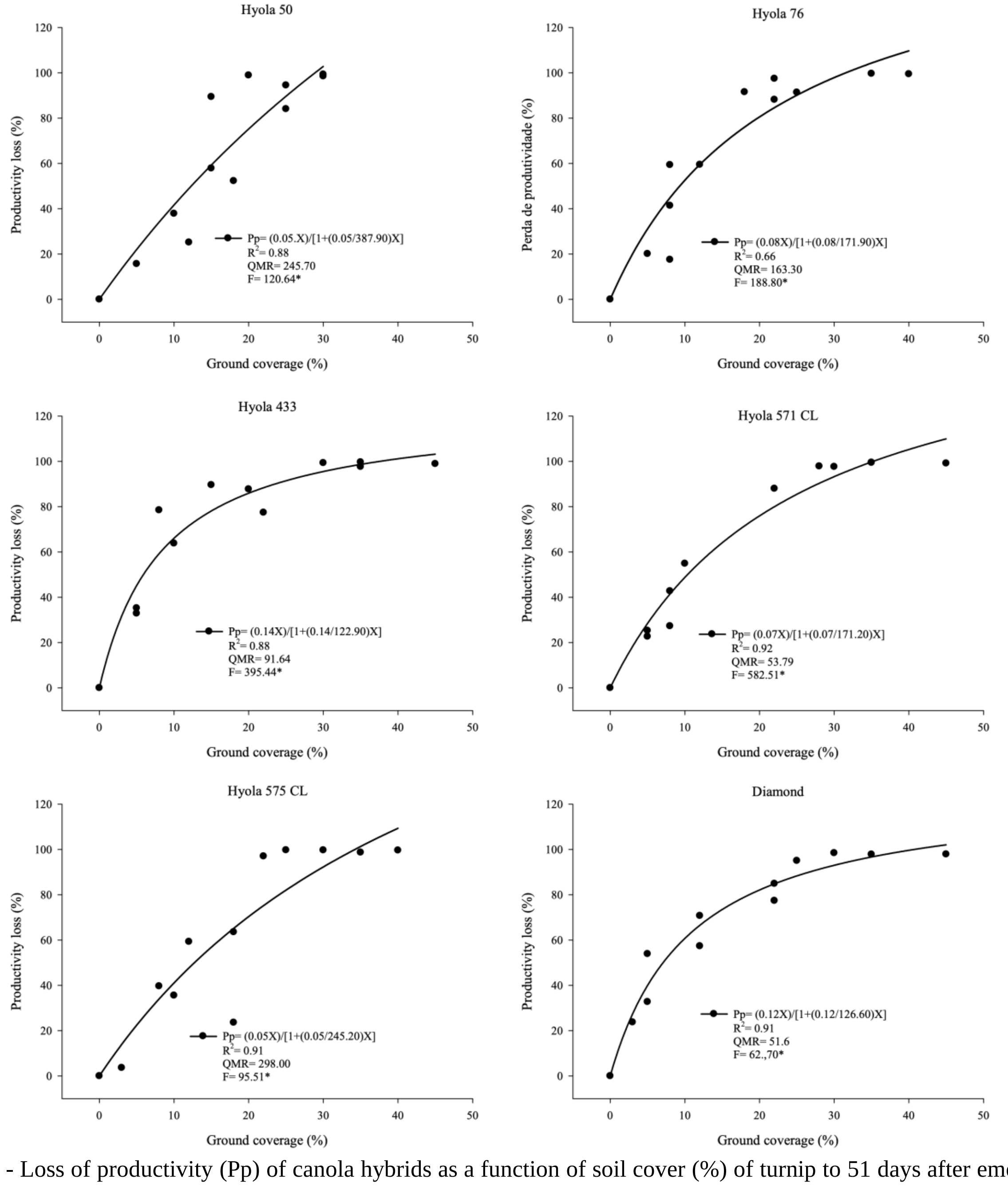

Fig. 3 - Loss of productivity (Pp) of canola hybrids as a function of soil cover (%) of turnip to 51 days after emergence. UFFS, Erechim/RS, 2018. R^2 = Coefficient of determination; QMR: mean square of residue; * Significant at $p \leq 0.05$.

The observed differences between the results of the hybrids can be attributed to the set of morphological characteristics inherent to the differences that exist between the cultivars of the same species (KALSING, VIDAL, 2013), the best use of available resources in the medium (light, water and nutrients), some management practices (AGOSTINETTO et al., 2010) and also the standard error in the parameter *i* estimation, which can be attributed to the variability associated with field experimentation and the phenotypic plasticity of the crop (STREIBIG et al., 1989).

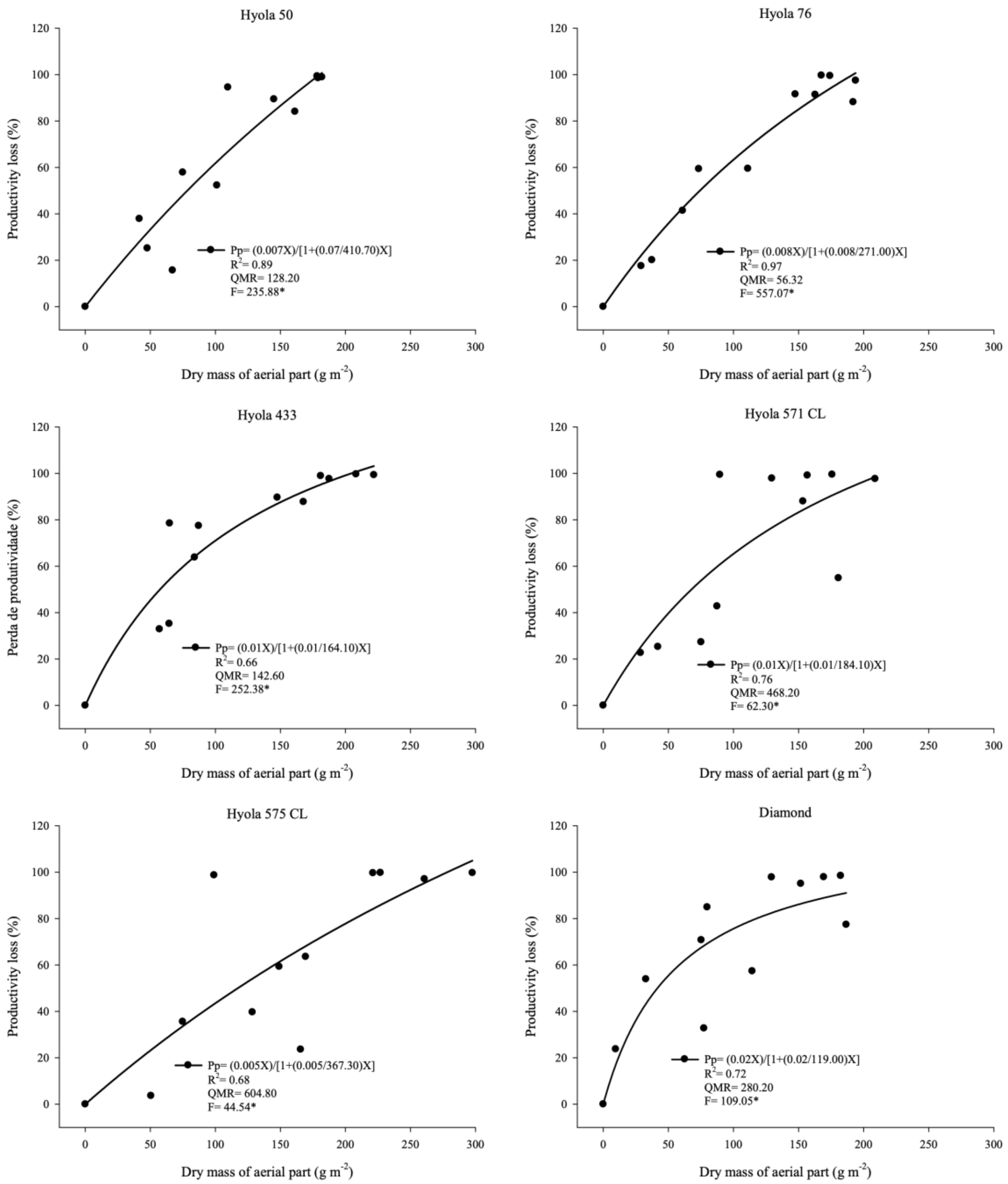

Fig. 4 - Loss of productivity (Pp) of canola hybrids as a function of dry mass of the aerial part (g m^{-2}) of turnip at 51 days after emergence. UFFS, Erechim / RS, 2018. R^2 = Coefficient of determination; QMR: mean square of residue; * Significant at p≤0.05.

When comparing the canola hybrids for the PP variable, based on the unit loss (i), productivity losses of 1.53 were observed: 1.80, 4.30, 1.97, 1.46 and 4.61% for Hyola 50, Hyola 76, Hyola 433, Hyola 571 CL, Hyola 575 CL and Diamond, respectively (Fig. 1). Williams et al. (2008) attributed the difference in competition of maize hybrids to higher canopy (AF) and plant height, resulting in greater efficiency in light interception, leading to the greater suppression of weeds. The competition imposed by the genetic material becomes a potential strategy for integrated weed management in current control programs (JHA et al., 2017) which may lead to a reduction in the use of herbicides.

The results show that the increase in the turnip population to about 400 plants m^{-2} demonstrated a loss of productivity of the canola hybrids in approximately 100%, and even with the increase of the weed populations, the losses had already reached its maximum point, compromising crop productivity and performance (Fig. 1).

The competitiveness of volunteer plant barley, oats, foxtail, caruru and wild mustard with canola and yellow mustard caused more significant losses in canola yield than in yellow mustard, when both were in competition with the naturally emergent weeds in the area (BECKIE et al., 2008). These same authors also mention that cultivars with high stature, rapid emergence and greater accumulation of biomass in the aerial part are more likely to be competitive.

The competition of the crop with the weed quantitatively and qualitatively affected the production of canola, since the weed modifies the efficiency of the crop in harnessing the resources available in the environment, such as water, light, CO_2 and nutrients (GALON et al., 2015).

There was an average loss of 0.70 and 3.41% of the productivity of the canola grain hybrids in the lowest AF (10000 cm^2 m^{-2}) and higher AF (50000 cm^2 m^{-2}), respectively (Fig. 2). The Hyola 575 CL and Hyola 433 hybrids presented the lowest and the highest loss with 38.46 and 134.10% in the FA of 10000 cm^2 m^{-2} and 39.31 and 134.78% in the FA of 50000 cm^2 m^{-2}, respectively. It can be inferred that the degree of hybrids in competition with the turnip is influenced by the leaf area of the weed, as also verified by Parreira et al. (2014) when evaluating the competition of carioca bean cultivars with weeds.

The turnip exerted greater competition on sugarcane (TIRONI et al., 2013) and also caused a decrease in rice leaf area and shoot dry mass (GALON et al., 2007); as in the weed population, there was a significant increase in yield losses of the crops studied.

The results for the loss of productivity of canola hybrids, in relation to the percentage of CS (Fig. 3), demonstrate similarity to that observed in relation to PP (Fig. 1). With 5% of CS of the turnip, the hybrids of canola presented losses of around 15% (Fig. 3). When CS approached 30% almost all canola hybrids showed losses close to 100%. This high competition between the crop and the turnip is due in part to both belonging to the same botanical family, which causes high competition for the resources of the environment and that, even in low populations, the weed present in the soil and during the initial stage of development causes severe losses to the crop.

The turnip has a large ability to branch and increase its height, causing greater shading than weed crops. This was also observed by Tironi et al. (2014) when they found that turnip caused a greater shade to the barley crop when compared to ryegrass, which diminishes the productivity and quality of the product harvested.

The turnip was developed along with the canola crop and, because it was a weed, that is, more rustic, it presented higher growth and consequently greater soil cover, causing the canola hybrids to suffer a reduction in grain yield (Fig. 3). Those species that have similar morphology and physiology tend to present very similar requirements, as previously reported, in relation to growth factors, making the competition for factors that are limited in the niche where they develop more intense (AGOSTINETTO et al., 2010).

When accumulating 200 g m^{-2} of dry mass, the turnip caused yield reductions of canola of 1.4, 1.6, 2.0, 2.0, 1.0 and 3.92%, respectively, for the cultivars Hyola 50, Hyola 76, Hyola 433, Hyola 571 CL, Hyola 575 CL and Diamond (Figure 4). Considering that turnip is one of the main weeds of canola and difficult to control with the use of herbicides due to the similar morphological characteristics presented by both, this amount of dry mass, even if inferior to that which can be produced by area, already causes high losses productivity. Forte et al. (2018), when evaluating the dry mass yield of different winter cover crops in the Alto Uruguai region of Rio Grande do Sul, reported that the turnip produced an average of 5.0 t ha^{-1}.

The competition between canola hybrids (Hyola 61, Hyola 76, Hyola 433 and Hyola 571 CL) in the presence of turnip and/or ryegrass was impaired, regardless of the proportion of plants present in the study environment; in all cases, this caused a reduction of leaf area and dry weight of the species (GALON et al., 2015).

Kalsing and Vidal (2013) also found that bean cultivars, when competing with the papua, presented different behaviors related to the intrinsic characteristics that they demonstrate, as previously reported. Other authors also affirm that there are differences between cultivars when competing with weeds, attributing this to characteristics such as growth habit, development cycle and number of branches, among others, that affect the competitive ability of the crop and causes differentiation between the cultivars (PARREIRA et al., 2014).

Plants that come to establish themselves first in a given community are theoretically favored in the competition process, or because they possess differentiated characteristics such as greater stature, greater leaf area index, produce more green or dry mass, or have a larger root system, in which a particular cultivar or hybrid will demonstrate greater competitive ability (FORTE et al., 2017).

The estimates of parameter a, regardless of the explanatory variable, were overestimated by the model, with yield losses higher than 100% for all of the hybrids tested, except the PP for Hyola 575 CL and Diamond, in which losses were found to be below 100% (Fig. 1, 2, 3 or 4). These results may be due to the fact that the largest populations of turnip plants are not sufficient to adequately estimate the maximum yield loss of canola (COUSENS, 1991).

According to Cousens (1991), in order to obtain a reliable estimate for this parameter, it is necessary to include very high populations of weeds in the experiment, above those commonly found under tillage conditions. Similarly, Galon et al. (2007), studied rice competition with ricegrass subjected to different management methods, and also found losses greater than 100% for parameter a.

An alternative to avoiding productivity losses being overestimated would be to limit the maximum loss to 100%. However, the limitation will influence the estimation of parameter i and may result in less predictability in the rectangular hyperbola model (STREIBIG, COMBELLACK, 1989). In addition, yield losses greater than 100% are biologically unrealistic and occur when the range of weed populations is excessively narrow and/or when the highest population values are not sufficient to produce an asymptotic response to yield loss (AGOSTINETTO et al., 2010).

For hybrids of the same growth cycle, it was observed that the explanatory variables presented differentiated i-parameters (Fig. 1, 2, 3 or 4). Similarly, Kalsing and Vidal (2013) stated that cultivars of the same cycle demonstrated differentiated competitiveness, being expressed by parameter *i*. The authors report that this occurs, among other factors, because of the productivity differences that the cultivars present, which causes less loss of yield per weed individual, which corroborates with the result found in the present work where the Hyola 575 CL hybrid presented 0.88 t ha^{-1} compared to Hyola 50, Hyola 76, Hyola 433, Hyola 571 CL and Diamond with yields of 1.04, 1.07, 1.52, 1.18 and 2.09 t ha^{-1}, respectively, in the absence of competition.

The comparison between the explanatory variables for all canola hybrids, in general, showed a better fit to the model for the variables CS > PP > MS > FA, considering the higher mean values of R^2, F and the lower mean values of the QMR (Fig. 1, 2, 3 and 4), thus showing that CS can be used instead of the PP variable. It should be emphasized that the two variables (CS and PP) that demonstrate the best adjustments to the rectangular hyperbola model are easy and fast to determine, along with the low cost of the determination of yield losses of canola to field grains.

In order to perform the simulation of the values of economic damage level - EDL, the explanatory variable loss of productivity (PP) of canola was used, because this is the most used in experiments with this objective (AGOSTINETTO et al., 2010; KALSING, VIDAL, 2013; GALON et al., 2019). It should be noted that this variable has some advantages over others, such as ease, speed and low cost for determination (TIRONI et al., 2013).

Calculations of economic damage levels of turnip canola

In order to obtain success in the implantation of systems that aim at the management of weeds of the canola crop, it is necessary to make a determination in the population that surpasses the EDL. In this way, Hyola 50, Hyola 76, 571 CL and Hyola 575 CL showed the highest values of EDL in all the simulations performed, with variations ranging from 2.22 to 6.22 plants m^{-2} (Fig. 5, 6, 7 or 8). The lowest EDL values were obtained with hybrids Hyola 433 and Diamond, with variations from 0.95 to 2.11 plants m^{-2}.

On average, when all hybrids were compared from the lowest to the highest grain yield, a difference in EDL was observed in the order of 50% (Fig. 5). Thus, the higher the productive potential of the hybrids, the lower the population of turnip plants needed to overcome the EDL, and the control of the turnip will be compensatory. Exploration of the competitive capacity of an expressed culture is essential for the development of low-cost and sustainable weed management practices (JHA et al., 2017).

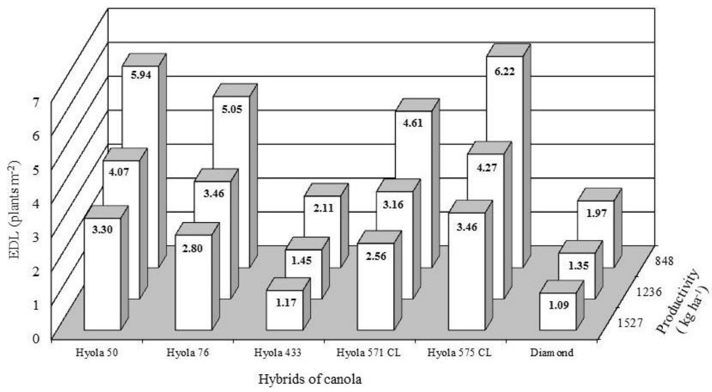

Fig. 5 - Economic damage level (EDL) as a function of grain yield, turnip population and canola hybrids.

The average results of all hybrids, from the highest to the lowest price paid for the canola bag, showed a 1.9-fold increase in the EDL value (Fig. 6). Consequently, the lower the price paid for the sack of canola, the greater the population needed to turn over the EDL and compensate for the control method. For management programs that use the EDL tool as a function of the price paid for the canola bag, the most competitive hybrids were Hyola 50, Hyola 76, Hyola 571 CL and Hyola 575 CL, and the less competitive Hyola 433 and Diamond.

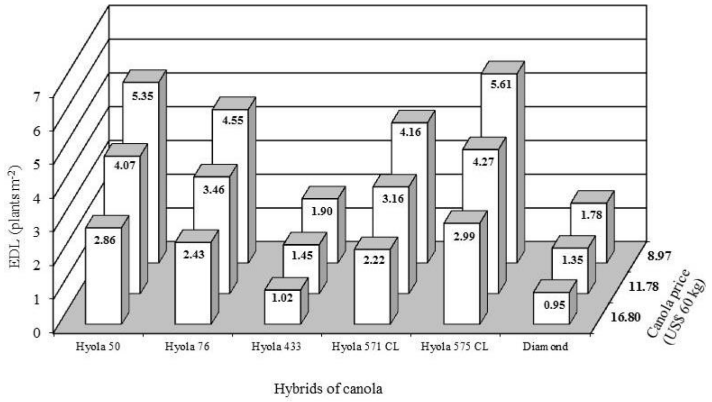

Fig. 6 - Economic damage level (EDL) as a function of grain price, turnip population and canola hybrids.

Regarding the efficiency of the chemical control method using the herbicide, it was observed that the average efficiency (90%), when compared with the lowest (80%) or highest (100%), has changes in EDL that vary by 25.0, 11.0, 12.5, 11.0, 11.5 and 11.5% for hybrids Hyola 50, Hyola 76, Hyola 433, Hyola 571 CL, Hyola 575 CL and Diamond, respectively (Fig. 7). Thus, the level of control influences EDL, and the higher the herbicide efficiency, the lower the EDL; that is, the lower number of m^{-2} turnip plants required to adopt control measures, a fact that was also verified by Agostinetto et al. (2010), when studying the interference of ricegrass in rice, and Galon et al. (2019), when working with wheat cultivars infested by ryegrass.

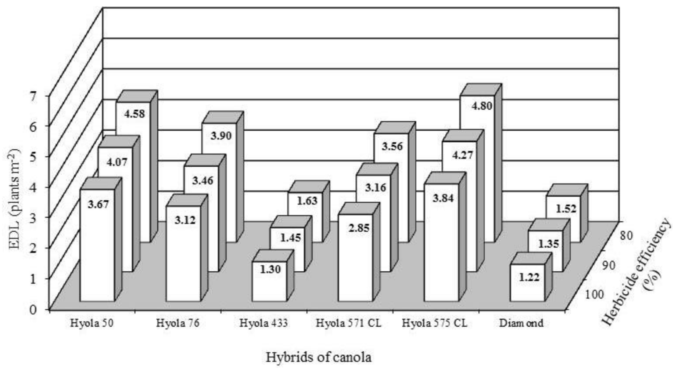

Fig. 7 - Economic damage level (EDL) as a function of herbicide efficiency, turnip population and canola hybrids.

Considering the average cost of turnip control in all hybrids, it was found that the minimum cost was 40% lower when compared to the maximum cost. In this way, it can be seen that the higher the cost of the control method, the higher the EDLs, and consequently more m^{-2} turnip plants are needed to justify the control measures (Fig. 8).

In order to use EDL as a tool in weed management, this should be associated with good agricultural practices in the management of canola, since its implementation is only evident in crops that use an adequate system of crop rotation, suitable plants, the use of more competitive cultivars, adequate sowing times, corrected soil fertility, areas without turnip infestation, and soil without compaction, among other innumerable strategies to increase production.

It is necessary to increase food production, since the world population will be 9 billion people by 2050 (WESTWOOD et al., 2018). With this, it is imperative that we seek new methods of producing food and controlling weeds. The weeds have caused high losses of productivity and quality of the product harvested, besides being host of pests. In many situations, the unnecessary use of herbicides to control weeds has contaminated the environment, raising production costs, and increasing resistance (KAMKAR et al., 2014).

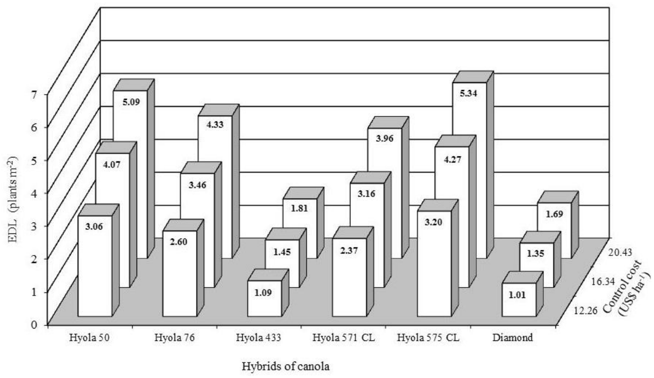

Fig. 8 - Economic damage level (EDL) as a function of control cost, turnip population and canola hybrids.

EDL can be used with a trend that will help to reduce the use of herbicides and favor the production of safer foods; as stated by Shaner and Beckie (2014) and Westwood et al. (2018), we need new strategies, or even the integration of old and new technologies in the management of plants in the most diversified production systems.

Research has shown that there is a differentiation in the competitive ability of weed-infested crops, this can be attributed to the fact that they present a set of morphological characteristics that are inherent to them (KALSING, VIDAL, 2013; PARREIRA et al., 2014).

Galon et al. (2015), when studying the competitiveness of canola versus ryegrass and turnip, observed that the competition between plants of the same family was more damaging in all evaluated items, since they competed for the same ecological niche. In this way, the identification of the most competitive cultivars or hybrids with weeds becomes interesting to adopt some control method when they reach the EDL and can also use fewer herbicides to handle them, with lower costs and less environmental contamination.

Conclusions

The nonlinear regression model of the rectangular hyperbola adequately estimates the yield losses of canola in the presence of turnip plants. The presence of an m^{-2} turnip plant causes an average grain yield loss varying between 1.5 and 4.6%, depending on the hybrid. The levels of economic damage to the turnip vary according to the hybrids of canola and weed populations. The levels of economic damage levels range from 2.86 to 5.95, 2.43 to 5.05, 2.22 to 5.43, and 2.99 to 6.22 turnip plants m^{-2} for the hybrids Hyola 50, Hyola 76, Hyola 571 CL and Hyola 575 CL, respectively, as a function of simulated variables. Hyola 575 CL, Hyola 50, Hyola 76 and Hyola 571 CL showed the highest competitiveness with the turnip, presenting values of economic damage levels of 2.22 to 6.22 plants m^{-2} of the weed in all of the variables studied. Increases in grain yield, canola price, herbicide efficiency and the reduction of control costs reduce the level of economic damage, justifying the adoption of control measures in smaller turnip populations.

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References

AGOSTINETTO, D.; GALON, L.; SILVA, J. M. B. V.; TIRONI, S. P.; ANDRES, A. Interferência e nível de dano econômico de capim-arroz sobre o arroz em função do arranjo de plantas da cultura. **Planta Daninha**, v. 28, p. 993-1003, 2010. https://www.scielo.br/j/pd/a/gbW3N7yx6PYJDSvqVNYTvMv/abstract/?lang=pt

BECKIE, H. J.; JOHNSON, E. N.; BLACKSHAW, R. E.; GAN, Y. Productivity and quality of canola and mustard cultivars under weed competition. **Canadian Journal of Plant Science**, v. 88, n. 2, p. 367-372, 2008. https://cdnsciencepub.com/doi/10.4141/CJPS07152

BERTHOLDSSON, N-O. Breeding spring wheat for improved allelopathic potential. **Weed Research**, v. 50, n. 1, p. 49-57, 2010. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-3180.2009.00754.x

BIANCHI, M. A.; FLECK, N. G.; LAMEGO, F. P. Proporção entre plantas de soja e plantas competidoras e as relações de interferência mútua. **Ciência Rural**, v. 36, n. 5, p. 1380-1387, 2006. https://www.scielo.br/j/cr/a/hJBHQ9p6S9PPBF7SGVV8Nvz/?lang=pt

CARGNELUTTI FILHO, A.; STORCK, L. Estatísticas de avaliação da precisão experimental em ensaios de cultivares de milho. **Pesquisa Agropecuária Brasileira**, v. 42, n. 1, p. 17-24, 2007. https://www.scielo.br/j/pab/a/d3mHzTnVPB8Vg3Hvg37xC3Q/?lang=pt

CONAB – Companhia Nacional de Abastecimento. **Monitoring the Brazilian Harvest, 2020**. https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de-graos?limitstart=0. [In Portuguese].

CEMET-RS. Centro Estadual de Meteorologia. Porto Alegre - RS, 2012.

COUSENS, R. An empirical model relating crop yield to weed and crop density and a statistical comparison with other models. **The Journal of Agricultural Science**, v. 105, n. 3, p. 513-521, 1985. https://www.cambridge.org/core/journals/journal-of-agricultural-science/article/abs/an-empirical-model-relating-crop-yield-to-weed-and-crop-density-and-a-statistical-comparison-with-other-models/4865A8FF88869023B6493B76960A5F42

COUSENS, R. Aspects of the design and interpretation of competition (interference) experiments. **Weed Technology**, v. 5, n. 3, p. 664-673, 1991. https://www.cambridge.org/core/journals/weed-technology/article/abs/aspects-of-the-design-and-interpretation-of-competition-interference-experiments/FF65740EE9D4E6BFB41D5861B07DF6C9#

EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária. **Brazilian System of Soil Classification**. 3st edition. Brasília: Embrapa Solos, 2013, 353p. https://livimagens.sct.embrapa.br/amostras/00053080.pdf. [In Portuguese].

FORTE, C. T.; BASSO, F. J. M.; GALON, L.; AGAZZI, L. R.; NONEMACHER, F.; CONCENÇO, G. Habilidade competitiva de cultivares de soja transgênica convivendo com plantas daninhas. **Revista Brasileira de Ciências Agrárias**, v. 12, n. 2, p. 185-193, 2017. http://www.agraria.pro.br/ojs32/index.php/RBCA/article/view/v12i2a5444

FORTE, C. T.; GALON, L.; BEUTLER, A. N.; BASSO, F. J. M.; NONEMACHER, F.; REICHERT JÚNIOR, F. W.; PERIN, G. F.; TIRONI, S. P. Soil management systems and their effect on the weed seed bank. **Pesquisa Agropecuária Brasileira**, v. 53, n. 4, p. 435-442, 2018. https://www.scielo.br/j/pab/a/GMLjSbGrPYyqRxnpFFZBF5m/?lang=en

GALON, L.; AGOSTINETTO, D.; MORAES, P. V. D.; DAL MAGRO, T.; PANOZZO, L. E.; BRANDOLT, R. R.; SANTOS, L. S. Níveis de dano econômico para decisão de controle de capim-arroz (*Echinochloa* spp.) em arroz irrigado (*Oryza sativa*). **Planta Daninha**, v. 25, n. 4, p. 709-718, 2007. https://www.scielo.br/j/pd/a/MpmZNmkW9qVGQWzTBS3sQsR/?lang=pt

GALON, L.; GUIMARÃES, S.; LIMA, A. M.; RADUNZ, A. L.; BEUTLER, A. N.; BURG, G. M.; ZANDONÁ, R. R.; PERIN, G. F.; BASTIANI, M. O.; BELARMINO, J. G.; RADUNZ, L. L. Competitive interaction of rice genotypes against alexandergrass. **Planta Daninha**, v. 32, n. 3, p. 533-542, 2014. https://www.scielo.br/j/pd/a/45TbrTJHRRgHdGFq6wC9x7B/abstract/?lang=en

GALON, L.; AGAZZI, L. R.; VARGAS, L.; NONEMACHER, F.; BASSO, F. J. M.; PERIN, G. F.; FERNANDES, F. F.; FORTE, C. T.; ROCHA, A. A.; TREVISOL, R.; WINTER, F. L. Competitive ability of canola hybrids with weeds. **Planta Daninha**, v. 33, n. 3, p. 413-423, 2015. https://www.scielo.br/j/pd/a/Z9LChg4cPLMXKQPk53t5sfg/?lang=en

GALON, L.; BASSO, F. J. M.; CHECHI, L.; PILLA, T. P.; SANTIN, C. O.; BAGNARA, M. A. M.; FRANCESCHETTI, M. B.; CASTOLDI, C. T.; PERIN, G. F.; FORTE, C. F. Weed interference period and economic threshold level of ryegrass in wheat. **Bragantia**, v. 78, n. 3, p. 409-422, 2019. https://www.scielo.br/j/brag/a/GcTSk9rzM6PJwPqxGXptfHt/?lang=en

JHA, P.; KUMAR, V.; GODARAA, R. K.; CHAUHAN, B. S. Weed management using crop competition in the United States: A review. **Crop Protection**, v. 95, p. 31-37, 2017. https://www.sciencedirect.com/science/article/abs/pii/S0261219416301533

KALSING, A.; VIDAL, R. A. Nível crítico de dano de papuã em feijão-comum. **Planta Daninha**, v. 31, n. 4, p. 843-850, 2013. https://www.scielo.br/j/pd/a/JnfzBFf88ddwHH5F84czfpz/abstract/?lang=pt

KAMKAR, B.; DORRI, M. A.; SILVA, J. A. T. Assessment of land suitability and the possibility and performance of a canola (*Brassica napus* L.) - soybean (*Glycine max* L.) rotation in four basins of Golestan province, Iran. **The Egyptian Journal of Remote Sensing and Space Science**, v. 17, n. 1, p. 95-104, 2014. https://www.sciencedirect.com/science/article/pii/S111098231300032X

KAUR, S.; KAURA, R.; CHAUHAN, B. S. Understanding crop-weed-fertilizer-water interactions and their implications for weed management in agricultural systems. **Crop Protection**, v. 103, p. 65-72, 2018. https://www.sciencedirect.com/science/article/abs/pii/S0261219417302806

KIRKEGAARD, J. A.; LILLEY, J. M.; BRILL, R. D.; WAREA, A. H.; WALELA, C. K. The critical period for yield and quality determination in canola (*Brassica napus* L.). **Field Crops Research**, v. 222, p. 180-188, 2018. https://www.sciencedirect.com/science/article/abs/pii/S0378429018302843

LINDQUIST, J. L.; KROPFF, M. J. Applications of an ecophysiological model for irrigated rice (*Oryza sativa*)-*Echinochloa* competition. **Weed Science**, v. 44, n. 1, p. 52-56, 1996. https://www.cambridge.org/core/journals/weed-science/article/abs/applications-of-an-ecophysiological-model-for-irrigated-rice-oryza-sativaechinochloa-competition/638FB3A012CDB3DB544BE1EF7ADBEAF7

LEMERLE, D.; LUCKETT, D. J.; WU, H.; WIDDERICK, M. J. Agronomic interventions for weed management in canola (*Brassica napus* L.) - A review. **Crop Protection**, v. 95, p. 69-73, 2017. https://www.sciencedirect.com/science/article/abs/pii/S0261219416301636

LOWRY, C. J.; SMITH, R. G. Weed Control Through Crop Plant Manipulations. *In*: **Non-Chemical Weed Control**, p.73-90, 2018. https://www.sciencedirect.com/science/article/pii/B978012809881300005X

PARREIRA, M. C.; ALVES, P. L. C. A.; LEMOS, L. B.; PORTUGAL, J. Comparação entre métodos para determinar o período anterior à interferência de plantas daninhas em feijoeiros com distintos tipos de hábitos de crescimento. **Planta Daninha**, v. 32, n. 4, p. 727-738, 2014. https://www.scielo.br/j/pd/a/gzYzTpzM3f5sjLLFx5cvzRC/abstract/?lang=pt

ROLAS – Rede Oficial de Laboratórios de Análise de Solo e de Tecido Vegetal. **Manual de calagem e adubação para os Estados do Rio Grande do Sul e de Santa Catarina**. Sociedade Brasileira de Ciência do Solo - Núcleo Regional Sul – [s. l.]: Comissão de Química e Fertilidade do Solo, 2016, 376p. https://www.sbcs-nrs.org.br/docs/Manual_de_Calagem_e_Adubacao_para_os_Estados_do_RS_e_de_SC-2016.pdf

SBCPD – Sociedade Brasileira da Ciência das Plantas Daninhas. **Procedures for installation, evaluation and analysis of experiments with herbicides**. Londrina/PR/BR: SBCPD, 1995, 42p. https://www.bdpa.cnptia.embrapa.br/consulta/busca?b=ad&id=943148&biblioteca=vazio&busca=autoria:%22GAZZIERO,%20D.%20L.%20P.%20(Coord.).%22&qFacets=autoria:%22GAZZIERO,%20D.%20L.%20P.%20(Coord.).%22&sort=&paginacao=t&paginaAtual=1. [In Portuguese].

SHANER, D. L; BECKIE, H. J. The future for weed control and technology. **Pest Management Science**, v. 70, n. 9, p. 1329-1339, 2014. https://pubmed.ncbi.nlm.nih.gov/24339388/

STREIBIG, J. C.; COMBELLACK, J. H.; PRITCHARD, G. H.; RICHARDSON, R. G. Estimation of thresholds for weed control in Australian cereals. **Weed Research**, v. 29, n. 2, p. 117-126, 1989. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-3180.1989.tb00849.x

SWINTON, S. M.; BÜHLER, D. D.; FORCELLA, F.; GUNSOLUS, J. L.; KING, R. P. Estimation of crop yield loss due to interference by multiple weed species. **Weed Science**, v. 42, n. 1, p. 103-109, 1994. https://www.cambridge.org/core/journals/weed-science/article/abs/estimation-of-crop-yield-loss-due-to-interference-by-multiple-weed-species/8AB3CCC68651BCBBE0CB04D5D33DDE06

TIRONI, S. P.; FIALHO, C. M. T.; FARIA, A. T.; GALON, L.; SILVA, A. A.; BARBOSA, M. H. P. Interferência de populações de *Brachiaria brizantha* na produtividade de cultivares de cana-de-açúcar. **Revista Brasileira de Ciências Agrária**, v. 8, n. 1, p. 21-26, 2013. https://www.redalyc.org/pdf/1190/119025752015.pdf

TIRONI, S. P.; GALON, L.; SILVA, A. F.; FIALHO, C. M. T.; ROCHA, P. R. R.; FARIA, A. T.; ASPIAZU, I.; FORTE, C. T.; SILVA, A. A.; RADÜNZ, A. L. Época de emergência de azevém e nabo sobre a habilidade competitiva da cultura da cevada. **Ciência Rural**, v. 44, n. 9, p. 1527-1533, 2014. https://www.scielo.br/j/cr/a/wGTJjXYszn6PWf6RRbnYZwp/abstract/?lang=pt

TOMM, G. O.; FERREIRA, P. E. P.; AGUIAR, J. L. P.; CASTRO, A. M. G.; LIMA, S. M. V.; MORI, C. **Panorama atual e indicações para aumento de eficiência da produção de canola no Brasil**. Passo Fundo: Embrapa Trigo. Documentos Online, 118, 2009, 27p. http://www.cnpt.embrapa.br/biblio/do/p_do118.htm

VARGAS, L.; TOMM, G. O.; RUCHEL, Q.; KASPARY, T. E. **Seletividade de herbicidas para a canola PFB-2**. Passo Fundo: Embrapa Trigo. Documentos Online, 130, 2011, 14p. http://www.cnpt.embrapa.br/biblio/do/p_do130.pdf

WESTWOOD, J. H.; CHARUDATTAN, R.; DUQUE, S. O.; FENNIMORE, S. A.; MARRONE, P.; SLAUGHTER, D. C.; SWANTON, C.; ZOLLINGER, R. Weed management in 2050: Perspectives on the future of weed science. **Weed Science**, v. 66, n. 3, p. 275-285, 2018. https://www.cambridge.org/core/journals/weed-science/article/weed-management-in-2050-perspectives-on-the-future-of-weed-science/51F98001554CADCE9866699E976562D1

WILLIAMS, M. M.; BOYDSTON, R. A.; DAVIS, A. S. Crop competitive ability contributes to herbicide performance in sweet corn. **Weed Research**, v. 48, n. 1, p. 58-67, 2008. https://onlinelibrary.wiley.com/doi/10.1111/j.1365-3180.2008.00602.x

WORTHINGTON, M.; REBERG-HORTON, S. C.; GUEDIRA, G. B.; JORDAN, D.; WEISZ, R.; MURPHY, J. P. Relative contributions of allelopathy and competitive traits to the weed suppressive ability of winter wheat lines against Italian ryegrass. **Crop Science**, v. 55, n. 1, p. 57-64, 2015. https://acsess.onlinelibrary.wiley.com/doi/full/10.2135/cropsci2014.02.0150

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