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ORIGINAL ARTICLE

Weed interference period and economic threshold level in barley

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Abstract

Determination of interference periods, competitive ability and economic threshold level (*ETL*) are important tools for integrated weed management (IWM) in barley. The objective of the work was to determine the periods of interference, the competitive ability and the *ETL* of weeds in barley (*Hordeum vulgare*). Two field experiments were carried out, in a randomized block design, with four replications. In this study, the periods of coexistence and control for ryegrass (*Lolium multiflorum*) and turnip (*Raphanus raphanistrum*) infesting barley cultivar, cv. ANA 01 were evaluated. The coexistence periods and/or control were: 0, 7, 14, 21, 28, 35, 42 and 120 days after barley emergence (DAE). In experiment 2the treatments for determination of *ETL*s were composed by barley cultivars (BRS Suábia, ANA 01, BRS Korbel, BRS Manduri, BRS Cauê and BRS Greta), and turnip densities, from zero (0) to maximum densities of 816, 788, 948, 394, 584 and 618 plants · m^{-2}, in competition with each cultivar. Control of turnip and ryegrass should be adopted in barley in the period between 12 to 22 DAE, which is described as a critical control period. The rectangular hyperbola adequately estimates losses in grain yield due to turnip infestation. There is an effect on the competitive ability of the cultivars in relation to turnip, which resulted in *ETL*s that ranged from 0.27 to 1.99 plants · m^{-2}. The cultivars BRS Greta, BRS Suábia, ANA 01 and BRS Manduri were the most competitive in the presence of turnip.

Keywords: critical period of competition, economic threshold level, integrated weed management

Introduction

The average Brazilian productivity of barley (*Hordeum vulgare* L.) grains is 3.62 t · ha^{-1}, which is far below those obtained in experimental areas or in other crops where high technologies are adopted (Conab 2021). Among the probable causes for the average reduction of approximately 1 t · ha^{-1} in barley grain yield, when comparing crops grown with high technology to those with low technology, is the interference caused by weeds which compete with the crop for resources like water, light and nutrients (Tironi *et al.* 2014; Pies *et al.* 2019; Galon *et al.* 2019). Weed infestation in barley can result in a grain yield reduction of up to 78% (Mahajan *et al.* 2020), caused by allelopathic effects or host pests and diseases, if they are not properly controlled (Tironi *et al.* 2014; Pies *et al.* 2019).

Weeds that infest barley include wild radish and/or turnip (*Raphanus raphanistrum* and/or *R. sativus*), ryegrass (*Lolium multiflorum* Lam.) and black or white oats (*Avena strigosa* Schreb. or *A. sativa* L.) because these species are very competitive for the resources available in the environment (Tironi *et al.* 2014; Pies *et al.* 2019; Mahajan *et al.* 2020). These species have shown resistance to herbicides that inhibit acetolactate synthase (ALS), acetyl-coenzyme A carboxylase (ACCase) and enol pyruvyl shiquimate phosphate synthase (EPSPs), making their chemical control difficult.

Weed control strategies in barley are important to minimize the damage caused by competition, especially by turnip and ryegrass in southern Brazil. This fact has led to a change in the cultivation system. Instead of completely controlling weeds, the current emphasis is on the management of their densities, based on the concept of economic threshold level – *ETL* (Paynter and Hills 2009; Galon *et al.* 2019; Tavares *et al.* 2019).

Applying tools available to study the competition between plants in a community, it is possible to highlight studies that take into account the periods of weed interference present in the ecosystem, in comparison to the crop (Swanton *et al.* 2015), and also *ETL*. Using plant density variables, soil cover, leaf area and dry mass of the shoots of the weeds, the *ETL* compares the losses of productivity with the control costs. This makes it possible to evaluate the gain obtained according to the treatment used (Agostinetto *et al.* 2010; Tavares *et al.* 2019; Galon *et al.* 2019). Studies on the interference and competitiveness of crops with weeds contribute to the development of more effective weed management strategies with less impact on the environment (Jha *et al.* 2017; Kumar and Jha 2017; Meulen and Chauhan 2017; Galon *et al.* 2019).

The damage level to crops, due to competition between the crops and weeds, is related to the time and coexistence periods (Tironi *et al.* 2014). In view of this, it is important to determine the coexistence period in which weeds cause damage to crop productivity, since this is the moment when weed control should be carried out. Through field trials it is possible to estimate the critical period of interference prevention (CPIP), a period during which it is necessary to carry out the control of weeds infesting crop (Kumar and Jha 2017). This experiment design has the advantage of easy establishment and conduction under field conditions (Swanton *et al.* 2015).

To estimate the *ETL*, regression equations or damage functions are adopted which are related to crop productivity losses due to weed infestation. All information related to production practices can play an important role in changing management strategy that depends mainly on herbicides, towards a system focused on ecophysiology or a more sustainable model (Mahajan *et al.* 2020; Galon *et al.* 2019; Tavares *et al.* 2019). Therefore, it is important to know the interactions that occur between plants in communities, making it possible to develop more efficient and sustainable strategies for the management of weeds in crops (Meulen and Chauhan 2017; Galon *et al.* 2019).

Sowing more competitive cultivars allows the producer to use fewer herbicides to control weeds. Mahajan *et al.* (2020), evaluating eight barley cultivars in competition with wild oat plants, reported that cultivars Commande and Westminster showed higher tillering capacity and plant height, which consequently led to higher grain yields. The barley cultivars Baudin, Flagship and Hamelin were more competitive in the presence of ryegrass, which led them to give higher grain yields than cultivars Buloke, Gairdner and Vlamingh (Paynter and Hills 2009). Galon *et al.* (2011), when studying different barley cultivars, observed that the 'BRS Elis' showed greater growth and consequently was more competitive than the BRS Greta and the BRS 225 when competing with different ryegrass densities.

Nowadays, it is necessary to produce better quality food which is free from contaminants, and to use pesticides and herbicides, which have less harmful effects on the environment caused by excessive use. Techniques that improve these negative aspects in agricultural production for environmental conservation and greater economic return for the producer are needed.

The tested hypothesis was that there are different morphological and productivity responses from barley cultivars in competition with turnip and ryegrass, both related to the interference periods as well as the competitive ability and *ETL*s. Therefore, the objective of this work was to determine the periods of interference, the competitive ability and the *ETL* of weeds infesting barley.

Materials and Methods

Descriptions and conduction locations of the experiment

Two experiments were installed in the experimental area of the Federal University Fronteira Sul, campus Erechim, in the 2015/16 crop year, with geographic coordinates 27°43'47" S and 52°17'37" W and an altitude of 670 m, in a no-tillage system. The vegetation was desiccated with the herbicide glyphosate (1,080 g · ha^{-1}) before sowing the barley. The experiments were set up next to each other. The first aimed to determine the periods of interference of ryegrass and turnip, while the second was carried out to analyze the economic threshold level of ryegrass infesting different barley cultivars.

The region's climate is classified as Cfa (humid temperate with hot summers) according to the Köppen-Geiger classification, in which rainfall is well distributed throughout the year (Peel *et al.* 2007). The climatic conditions during the experimental period are shown in Figure 1. The soil correction, classified as Aluminium-Iron humic Red Lactosoil (Santos *et al.* 2018) was carried out based on soil analysis, with the following characteristics: pH (water) = 5.1; organic

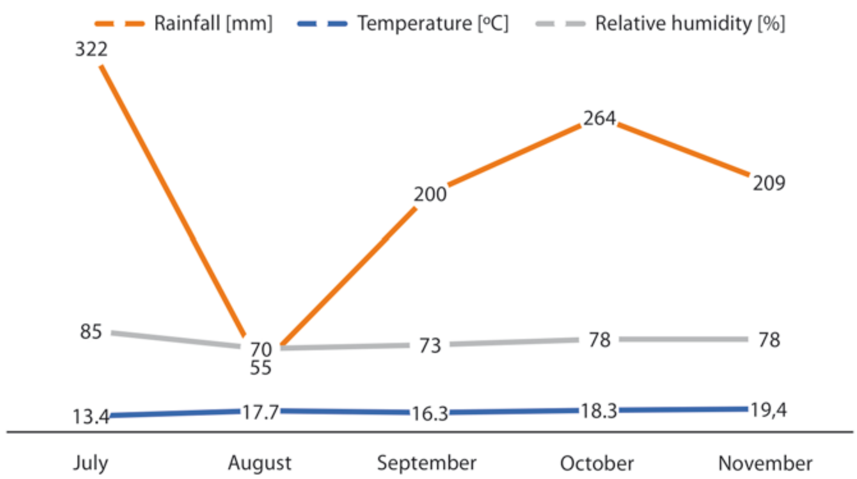

Fig. 1. Rainfall, temperature and average monthly relative humidity recorded during the execution of the experiments. UFFS, Campus Erechim/RS, 2015

matter = 3.0%; clay = >60%, silt = 30%; sand = 10%; P = 5.2 mg · dm^{-3}, K = 118 mg · dm^{-3}, Ca^{+2} = 5.5 cmolc · · dm^{-3}; Mg^{+2} = 3.0 cmolc · dm^{-3}; Al^{+3} = 0.3 cmolc · dm^{-3}; H^{+} Al = 7.7 cmolc · dm^{-3}; effective CTC = 16.6 cmolc · · dm^{-3}. The application of nitrogen 45% was 250 kg · ha^{-1} in the form of urea divided into two applications. The first application (125 kg · ha^{-1}) was at the beginning of barley tillering and the second dose (125 kg · ha^{-1}) was at the first visible node, according to the soil chemical analysis and expected crop yield.

Experimental units for the two experiments covered 11.05 m^2 (2.21 × 5 m), with sowing carried out in 13 rows, 5 m long and 0.17 m row spacing, totaling 2.21 m wide. Barley sowing density was 44 viable seeds per linear meter, which allowed for the establishment of a population of approximately 260 plants · m^{-2}.

To prevent insects and diseases, insecticides (chlorantraniliprole + lambda-cyhalothrine) and fungicides (azoxistrobine + epoxiconazol) recommended for barley crop were applied during the two field experiments. All other management practices used were those recommended by Minella (2013) for barley.

Experiment 1: Interference periods of turnip and ryegrass in barley

The experimental design used was randomized blocks, with four replications. Barley cultivar sown on July 13, 2015 was MN 610, with fertilization carried out in the sowing line, at a dose of 250 kg · ha^{-1} of the formula 05-30-15 of N-P-K.

The experiment was composed of two factors: periods of coexistence and control periods of turnip and ryegrass in the barley crop. During the coexistence period, the crop was maintained in the presence of weeds for initial increasing periods of: 0, 7, 14, 21, 28, 35, 42 and 120 days after emergence (DAE), after which the weeds were controlled. During the control period, the crop was kept free of turnip and ryegrass in the same periods described above. The plants that emerged after these intervals were no longer controlled.

Turnip and ryegrass removal was carried out with manual hoeing in each proposed period. A population survey was carried out in the experimental area, which showed an average population of 18 and 35 plants · m^{-2} for turnip and ryegrass, respectively. Plants came from the soil seed bank. The remaining weed species in the experimental area, not the object of study, were eliminated by weeding.

At the end of each coexistence or control periods, the dry mass of the shoots of crop and weeds (turnip and ryegrass) was quantified. To determine the dry mass of the crop, the plants were collected from 1 m of each row in each experimental unit. For the quantification of weed dry mass, a 0.25 m^2 square was used. The samples were dried in an oven with forced air circulation at 60 ± 5°C, until a constant mass was reached for later weighing and determination of the dry mass of plant shoots.

Plant height, number of plant stalks, chlorophyll index and leaf area were also evaluated at 42 DAE. At harvest, the number of ears per area (m^2), ear length (cm), number of full, sterile and total grains per ear, mass of 1,000 grains (g), hectoliter weight (kg · hl^{-1}) and barley productivity (kg · ha^{-1}) were determined. To determine plant height, chlorophyll index, number of full, sterile and total grains per ear and ear length, ten randomly chosen plants were used from each experimental unit. Plant height was measured using a graduated ruler, from close to the ground to the apex of the flag leaf. The number of stalks and ears were measured in the center of each experimental unit using a 0.5 × 0.5 m square. The chlorophyll content, which was the average of 10 observations in barley plants, was determined with a portable chlorophyll meter model SPAD 502 – Plus, for each experimental unit. Leaf area was measured using a portable meter model CI-203 Bio Science, quantifying it in 10 plants per treatment. Ear length was determined using a graduated ruler. By counting, effectuated at the Sustainable Management of Agricultural Systems Laboratory at UFFS, Campus Erechim, the number of full, sterile grains and the total grains per ear were determined.

At 130 DAE of the crop, grain yield was determined in an area of 3.0 m^2, when the grains had 15% moisture. After determining the moisture content of the grains, the mass of the samples was standardized to 13% and the results were expressed in kg · ha^{-1}. The mass of 1,000 grains was determined by counting eight samples of 100 grains each and later weighed in an analytical balance. The hectoliter weight (kg · hl^{-1}) was measured using a hectolitric weight balance.

Statistical analysis

All data were submitted to variance analysis by *F* test. When significant, the following analyses were realized: a) for dry mass of the crop and weeds, obtained at the end of each control or coexistence period, the treatments were compared by *T* test; b) plant height, number of stalks, chlorophyll index, leaf area, ear number per area, ear length, number of full, sterile grains and total grains per ear, mass of 1,000 grains and hectolitric weight were compared by Tukey's test (between the control or coexistence periods) and by *T* test (in each control or coexistence period), both $p \leq 0.05$; c) a three-parameter sigmoidal model was fitted to grain productivity, through the equation:

$$\hat{y} = a/(1 + e(-(x-x0)/\mathrm{b})),$$

where: $\hat{y}$ = barley grain yield; a = initial value of the equation; x = number of days after crop emergence; $x0$ = number of days on which 50% of the reduction occurs and b = slope of the curve.

The critical period of interference by turnip and ryegrass on barley was estimated by subtracting 5% from the average yield in the plots maintained without weed coexistence throughout the crop cycle. This value was considered as the cost of adopting chemical control.

Experiment 2: Competitive ability and economic threshold level of turnip in barley

The experiment was installed on July 13, 2015 in a randomized block design, with treatments composed of six barley cultivars (BRS Suábia, ANA 01, BRS Korbel, BRS Manduri, BRS Cauê and BRS Greta), and 10 turnip plant densities (0, 32, 32, 46, 81, 110, 260, 300, 344 and 816 plants · m^{-2} for BRS Suábia; 0, 14, 20, 22, 42, 48, 70, 92, 486 and 788 plants · m^{-2} for ANA 01; 0, 26, 28, 90, 94, 352, 656, 656, 694 and 948 plants · m^{-2} for BRS Korbel; 0, 16, 34, 48, 108, 128, 244, 376, 386 and 394 plants · m^{-2} for BRS Manduri; 0, 34, 44, 50, 54, 90, 144, 268, 436 and 584 plants · m^{-2} for BRS Cauê; and 0, 12, 14, 32, 42, 182, 242, 254, 456 and 618 plants · · m^{-2} for BRS Greta). Since the turnip seeds came from the soil seed bank, the establishment of densities was varied, because factors such as infestation, vigor, humidity and others, prevent the establishment of the exact number of plants per area (experimental unit). This was also reported in a study by Agostinetto *et al.* (2010) when evaluating the economic threshold level of barnyardgrass infesting irrigated rice. Barley cultivars were selected due to the genetic differences they possess and also because they are the most cultivated by Brazilian producers, having the characteristics described in Table 1.

Competitor densities were established from the soil seed bank by applying the herbicide metsulfuron-methyl (6.6 g · ha^{-1}) + emulsionable mineral oil (0.1% v/v), when the crop had four leaves and the weed was in the stage of two to six leaves. The herbicide metsulfuron-methyl was used in the experiment because it is registered and recommended for the control of turnip infesting barley crops in Brazil (AGROFIT 2021). The season was chosen because it was the most suitable for the application of a post-emergence herbicide on the barley crop. Turnip plants were protected with plastic

Table 1. Genetic characteristics of barley cultivars used in the study. UFFS, Campus Erechim/RS/BR

Company	Pedigree	Maturation cycle [days]	Size	Stature [m]
Embrapa	BRS Cauê	125–132	dwarf	0.80
Embrapa	BRS Korbel	125–135	medium low	0.80
Embrapa	BRS Manduri	115–125	dwarf	<0.80
Embrapa	BRS Suábia	103	medium	0.88
Embrapa	BRS Greta	100	dwarf	<0.80
Fapa-Agrária	Ana 01	137	medium low	0.81

Source: Minella (2013)

cups so as not to suffer injuries from the herbicide. The remaining weeds in the experimental units, not wanted for the study, were controlled by weeding.

The evaluated variables in turnip at 35 DAE (the period that coincides with the application of herbicides in post-emergence of weeds) were: plant density, dry mass of the shoots, leaf area and soil cover.

The quantification of the explanatory variable plant density was realized by counting the plants present in two squares of 0.25 m^2 (0.5 m × 0.5 m) per experimental unit (plot). Soil cover by turnip plants was evaluated visually by two independent evaluators, using a percentage scale, in which a score of zero corresponded to the absence of soil cover and a score of 100 represented total soil coverage. Quantification of leaf area ($cm^2 \cdot m^{-2}$), dry mass of the shoots ($g \cdot m^{-2}$) of radish and grain yield of barley cultivars was performed in the same way as described in experiment one (periods of interference).

Statistical analysis

With the grain yield data, percentage losses were calculated in relation to the plots kept without infestation (controls), according to Equation 1:

$$\text{Loss } [\%] = \frac{Ra - Rb}{Ra} \times 100, \qquad \text{(Eq. 1)}$$

where: Ra and Rb = crop productivity without the presence of the competitor plant or with it, respectively. Before submitted for data analysis, soil cover (%), leaf area ($cm^2 \cdot m^{-2}$) and dry mass of the shoots ($g \cdot m^{-2}$) values were multiplied by 100, thus eliminating the use of the correction factor in the model (Agostinetto *et al.* 2010; Galon *et al.* 2019).

Relations between percentage losses of barley productivity as a function of the explanatory variables were calculated separately for each cultivar, using the nonlinear regression model derived from the rectangular hyperbole, proposed by Cousens in 1985. Equation 2 was used to calculate productivity losses:

$$Pp = \frac{i \times X}{1 + \frac{i}{a} \times X}, \qquad \text{(Eq. 2)}$$

where: Pp = productivity losses (%); X = turnip density, soil cover, leaf area and dry mass of shoots; i and a = productivity losses (%) per unit of turnip, when the value of this variable tends to zero and when it tends to infinity, respectively.

For the calculation procedure, the Gauss-Newton method was used. By successive iterations, the values of the parameters were estimated, in which the sum of the squares of the deviations from observations, in relation to the adjusted values, is minimal (Agostinetto *et al.* 2010; Tavares *et al.* 2019). The value F statistic ($p \leq 0.05$) was used as a criterion for data analysis in the model. The criterion for accepting the fit of the data to the model was based on the highest value of the determination coefficient (R^2) and the lowest value of the mean square residue (MSR).

For the calculation of the economic damage threshold level (ETL), the estimates for parameter i, obtained from Equation 2 (Cousens 1985) and the Equation adapted from Lindquist and Kropff (1996) – Equation 3 were used:

$$ETL = \frac{Cc}{R \times P \times \frac{i}{100} \times \frac{H}{100}}, \qquad \text{(Eq. 3)}$$

where: ETL = economic threshold level ($\text{plants} \cdot m^{-2}$); Cc = control cost (herbicide and tractor application, in $\text{dollars} \cdot ha^{-1}$); R = barley grain yield ($kg \cdot ha^{-1}$); P = barley price ($\text{dollars} \cdot kg^{-1}$ grains); i = barley productivity loss (%) per unit of competing plant when the population level approaches zero and H = herbicide efficiency (%). For data simulation referring to the cost of control, the herbicide metsulfuron-methyl (4,0 $g \cdot ha^{-1}$) – Ally® (6,6 $g \cdot ha^{-1}$) + emulsionable mineral oil – Nimbus® (0.1% v/v) was applied since it is registered for the control of turnip in barley.

For variables: Cc, R, P and H (Eq. 3), three values which occurred 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 altered by 25%, in relation to the average cost. Barley productivity (R) was based on the lowest, average and highest obtained in Rio Grande do Sul, in the last 10 years. The price of the product (P) was estimated from the lowest, average and highest price of barley per 60 kg bag, in the last 10 years. The values for the efficiency of the herbicide (H) were established in the order of 80, 90 and 100% of control, with 80% being the minimum control considered effective for the weed (Velini *et al.* 1995). For the ETL simulations, intermediate values were used for the variables that were not being calculated.

Results and Discussions

Experiment of interference periods

The results regarding the accumulation of the dry mass of the shoot of turnip, ryegrass and barley showed significant differences between the control and the coexistence at 28 and 42; 14, 21 and 28; and 14, 28 and 35 DAE (days after emergence), respectively (Fig. 2A, B and C). Agostinetto *et al.* (2008) found a significant difference in the dry mass of the shoot of wheat at 42, turnip at 14, 28, 35 and 42, and ryegrass at 35 and 42

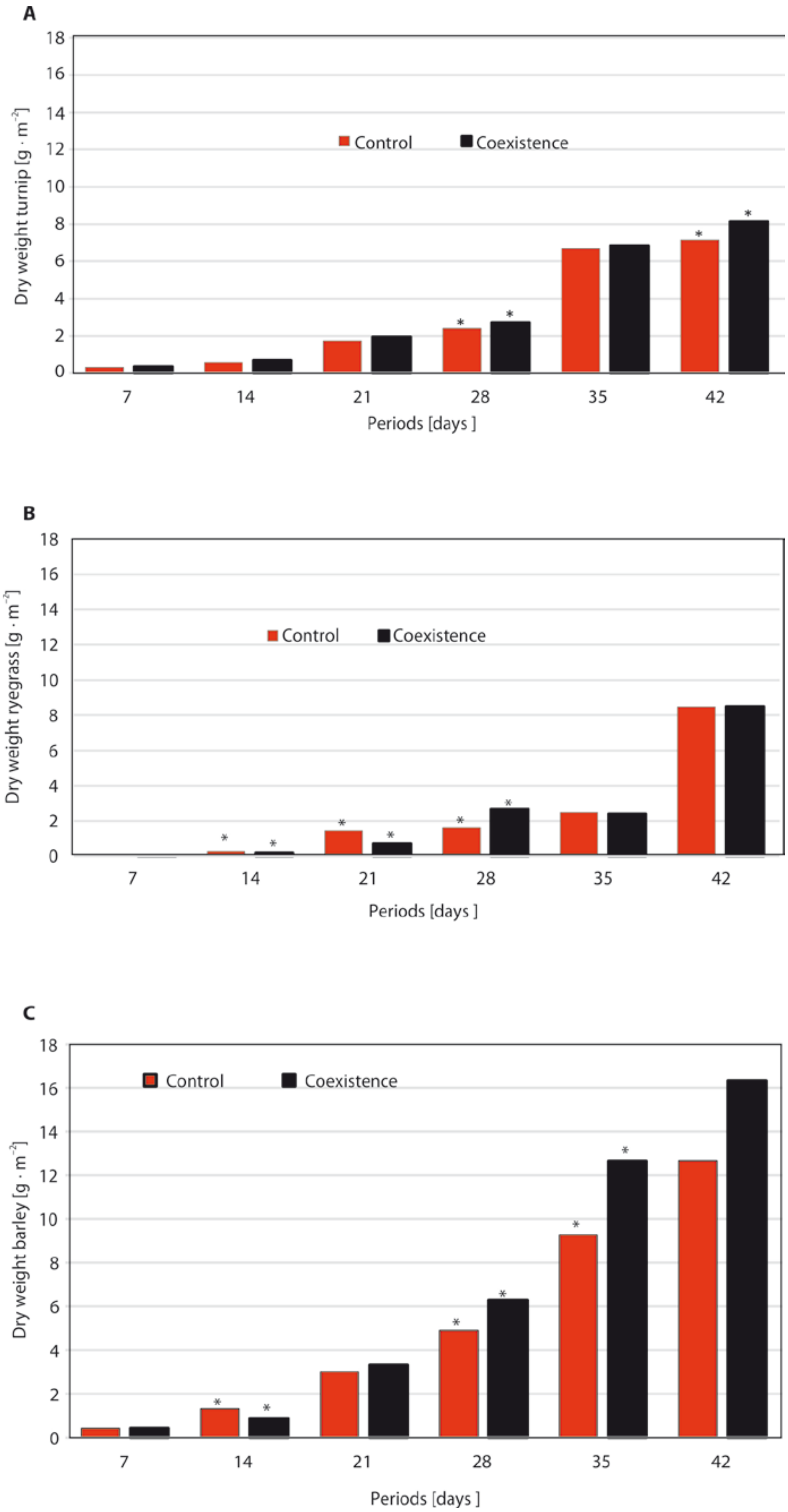

Fig. 2. Dry mass of the shoots of turnip (A), ryegrass (B) and barley (C) accumulated in each control or coexistence period with barley, where asteriks (*) indicates a significant difference between each period ($p \leq 0.05$). UFFS, Campus Erechim/RS

DAE, which are very similar to those observed in the present study. It is speculated that the different results may be related to different factors such as the species studied (barley and wheat) and also, the climatic and soil conditions existing between the different places where the work was carried out.

The accumulation of the dry mass of turnip shoots showed significant differences between the control and coexistence periods at 28 and 42 DAE (Fig. 2A). For Agostinetto *et al.* (2008) the production of dry mass by the turnip was higher in the coexistence periods than in the controls, for 14, 28 and 35 DAE. They attributed the result to lines between the crops, reducing the incidence of light, causing reduction of reinfestation in the periods kept under control.

Dry mass of ryegrass shoots showed significant differences in control and coexistence periods at 14, 21 and 28 *DAE* (Fig. 2B), and at 28 DAE. Ryegrass showed greater dry mass in the coexistence period than in the control. Total dry mass of several weed species (*Kochia scoparia, Amaranthus retroflexus, Chenopodium album* and *Fallopia convolvulus*) was higher in treatments where they lived with barley.

The delay in removing weeds, from the stage of 3 to 4 leaves to the stage of 8 to 10 leaves of barley, reduced crop biomass and increased weeds by 2.1 to 3.5 times, respectively (Kumar and Jha 2017).

Thus, it appears that early control of weeds is critical to improve competitiveness of barley when infested by different species of weeds. Furthermore, management of young plants is easier. Regarding the accumulation of ryegrass dry matter competing with wheat, Agostinetto *et al.* (2008) observed a longer coexistence period than in the control only at 35 and 42 DAE.

For barley, the accumulation of dry mass had significant differences between the periods of control and coexistence at 14, 28 and 35 DAE (Fig. 2C). It was possible to verify that only at 14 DAE the dry mass in the control period was greater. The results observed may occur due to the effect of the quality of light on the growth and development of barley plants due to the competition between the crop and weeds, as also reported by Paynter and Hills (2009). The quality of light can play a critical role in determining the emission, development and survival of tillers, and can be changed early in plant communities (Merotto Jr. 2009; Paynter and Hills 2009; Jha *et al.* 2017).

Barley height did not show significant differences between the control and coexistence periods, with an average of 33.00 cm in the control period, and 32.75 cm in the coexistence period (Table 2). Kumar and Jha (2017) also did not observe any differences when studying the coexistence of barley with several weed species, which is similar to what was found in the present work. There was a difference between control and coexistence only at 0 DAE for plant height. In other evaluated periods there was no differentiation. In a study carried out with wheat, Agostinetto *et al.* (2008) found no significant differences in plant height, both for the control period and for the coexistence period, which is in line with the observations in the present study.

Regarding the number of stalks, statistical significance and the highest value were observed at 7 DAE, both for control and coexistence periods (Table 2). Control of ryegrass and turnip at 7, 14 and 28 DAE caused a greater number of stalks than maintaining the crop living with weeds during these periods (Table 2). The absence of competition between the crop and turnip or ryegrass favored greater barley tillering and, consequently, a greater number of stalks per area. Galon *et al.* (2011) describe that when there is competition between crop and weeds, a smaller number of tillers is formed and, in this way, negative interference in the number of stalks occurs. Mahajan *et al.* (2020), who worked with barley genotypes in competition with weeds, reported that high tillering and crop height gives a competitive advantage when in the plant community.

Table 2. Plant height and number of stalks of barley cultivar MN 610 in each control and/or coexistence period with turnip and ryegrass. UFFS, Campus Erechim/RS

Days after emergence	Plant height [cm]		Number of stalks	
	control	coexistence	control	coexistence
0	*33.37 ns	31.77 ns	*131.33 ab	92.00 c
7	33.93	34.87	*160.67 a	126.50 a
14	34.23	32.83	116.00 b	104.50 bc
21	32.80	33.27	*130.50 ab	105.00 bc
28	31.47	33.00	*111.50 b	95.50 c
35	32.17	32.23	118.50 b	119.67 ab
42	32.63	31.30	124.33 b	108.00 bc
120	33.47	32.70	125.00 b	92.50 c

Means preceded by asterisk (*) in the lines, differ by the *t* test ($p < 0.05$), comparing control and coexistence periods with each other for each variable evaluated. Means followed by the same letter in the column do not differ by Tukey's test ($p < 0.05$); ns = not significant

Regarding the results obtained for the chlorophyll index, no differences were observed between the periods, but the best result was observed at 7 DAE and the worst at 42 DAE for the coexistence period (Table 3). According to Catunda *et al.* (2005), chlorophyll and carotenoid content in the leaves can indicate the damage level that certain stress can cause to the plant. The lowest chlorophyll index at 42 DAE may be related to the competition between weeds and the crop.

The results demonstrate no differentiation between the control or coexistence periods, nor between the control and coexistence within each period for barley leaf area (Table 3). This fact occurs due to faster emission and development of barley leaf area, which is faster than turnip and ryegrass covering the area. Thus, at the time when weeding was done, there was no effect of control or coexistence on the crop. Kumar and Jha (2017) when studying the infestation of *K. scoparia*, *A. retroflexus*, *C. album* and *F. convolvulus* in barley observed faster initial development of the crop than some of these weeds. The leaf area was responsible for covering between the lines, and consequently demonstrated greater competitiveness, with higher production of the dry mass of the shoots.

Growing periods, in which barley was kept in the absence of turnip or ryegrass, made it possible to calculate the period before interference (PBI). Thus, it was determined for cultivar MN 610 a PBI of 12 DAE, that, after 12 DAE, the losses were higher than the cost of control. The total period of interference prevention (TPIP), determined by the model, was up to 22 DAE. Thus, the 12 to 22 DAE interval is the critical period of interference prevention (CPIP), in which barley plants must be kept free of turnip and ryegrass plants (Fig. 3). The grain productivity losses increased according to the delay in the time of control of several weed species (Kumar and Jha 2017), which demonstrates the importance of turnip and ryegrass management as was seen in the present study, at the recommended time, to avoid losses to the producer.

Results found in the present research are similar to those observed by Agostinetto *et al.* (2008), where the authors determined the interference periods for FUNDACEP 52 wheat: PBI 12 DAE, TPIP 24 DAE and CPIP from 12 to 24 DAE when competing with ryegrass and turnip. Since no studies were found to assess the periods of weed interference in barley in Brazil, the research by Agostinetto *et al.* (2008) was used. They worked with wheat in competition with turnip and ryegrass.

The results regarding the number of full, sterile grains and total grains per ear show statistical differences only for the periods of coexistence, with the best results obtained at 0, 7, 14, 21 and 28 DAE (Table 4). There were no differences in each evaluated period between the control and coexistence of barley competing with the weeds. In initial stages (0 and 28 DAE), there was a greater number of full grains or total grains per ear and a fewer number of sterile grains for coexistence periods. This fact is probably linked to competition, in other words, the shorter the time that the crop is in the presence of weeds, the greater the productivity of full grains and lesser production of sterile grains. This probably occurs because it is in the early stage of the barley cycle that the crop defines the components of grain yield, thus requiring it to be free of stress determining factors, in this case, the presence of turnip and ryegrass.

The number of ears per area (m^2) and ear length (cm) did not show significant differences for the control and coexistence periods, or between the control

Table 3. Chlorophyll index (SPAD) and leaf area of barley cultivar MN 610 in each period of control and/or coexistence with turnip and ryegrass. UFFS, Campus Erechim/RS

Days after emergence	Chlorophyll index		Leaf area [$cm^2 \cdot plant^{-1}$]	
	control	coexistence	control	coexistence
0	*49.93 ns	47.76 ab	44.20 ns	38.70 ns
7	*49.25	50.30 a	45.93	46.60
14	49.97	47.92 ab	45.63	49.70
21	49.89	47.78 ab	44.70	41.93
28	49.95	48.35 ab	40.53	44.23
35	49.65	48.87 ab	37.80	40.83
42	48.06	46.75 b	41.47	40.23
120	47.95	48.99 ab	47.30	37.27

Means preceded by asterisk (*) in the lines, differ by t test ($p < 0.05$), comparing control and coexistence periods with each other for every variable evaluated. Means followed by the same letter in the column do not differ by Tukey's test ($p < 0.05$); ns = not significant

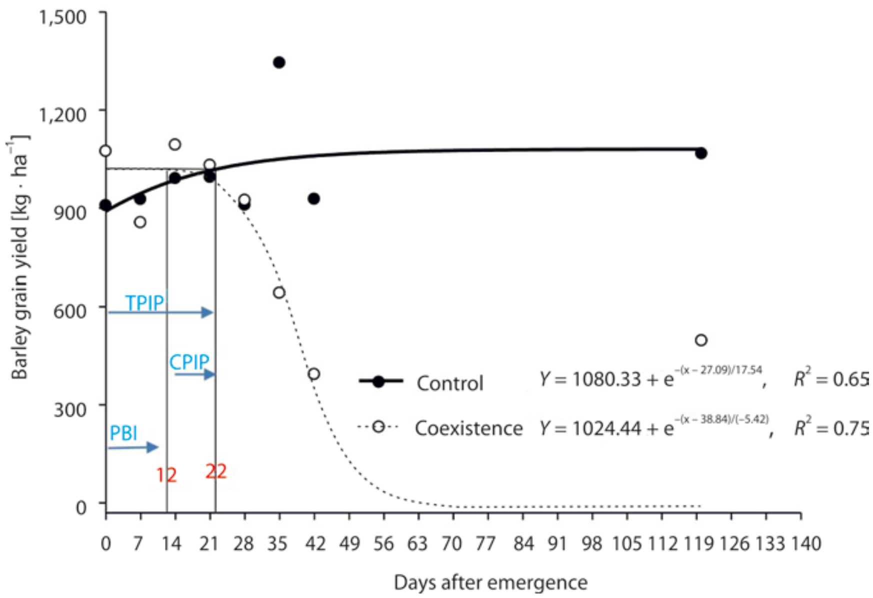

Fig. 3. Grain yield of MN 610 barley cultivar (kg · ha^{-1}), according to control (•) and coexistence (o) periods of *Lolium multiflorum* (ryegrass) and *Raphanus raphanistrum* (turnip). PBI = period before interference; TPIP = total period of interference prevention and CPIP = critical period of interference prevention. UFFS, Campus Erechim/RS

Table 4. Number of full, sterile grains and total grains per ear of MN 610 barley cultivar, in each period of control and/or coexistence with turnip and ryegrass. UFFS, Campus Erechim/RS

Days after emergence	Number of full grains per ear		Number of sterile grains per ear		Total number of grains per ear	
	control	coexistence	control	coexistence	control	coexistence
0	22.87 ns	22.53 abc	3.73 ns	2.80 b	26.60 ns	25.33 ab
7	22.33	22.93 abc	4.20	3.80 ab	26.53	26.73 ab
14	22.53	25.47 a	4.73	3.13 b	27.27	28.60 ab
21	23.87	24.87 ab	3.33	3.00 b	27.20	28.07 ab
28	19.60	25.07 ab	5.47	4.00 ab	23.73	29.07 a
35	21.93	18.53 c	5.47	6.53 a	27.40	24.40 b
42	22.93	20.53 abc	4.20	4.33 ab	27.13	24.87 b
120	25.80	19.67 bc	3.20	4.93 ab	29.00	24.60 b

Means followed by the same letter in the column do not differ by Tukey's test ($p < 0.05$); ns = not significant

and coexistence periods evaluated within each period (Table 5). The exception was for the number of ears at 120 DAE, when the control provided the best results. For the length of ears at 28 and 35 DAE, the best results were for coexistence. Lamego *et al.* (2013) when studying ryegrass and turnip infestation in different wheat cultivars found results similar to the present study.

For the mass of 1,000 grains (g) there was no statistically significant difference between the control and the coexistence of the weeds with barley or within each period (Table 6). For the hectoliter weight (khl) a lower value of the variable was observed than for the control at 28 DAE. Regarding coexistence, there were no differences between all evaluated periods. When comparing the control and coexistence with each other, within each period, there was no differentiation between them.

Galon *et al.* (2019), assessing the presence and absence of ryegrass in wheat, also did not find significant effects for the mass of 1,000 grains and the hectoliter weight of the crop, which corroborates with our results. According to Tavares *et al.* (2015), the hectoliter weight analyzed in different barley cultivars (BRS Elis and BRS Cauê) averaged 57.4 kg · hl^{-1}, a value very close to that found in the present study.

Table 5. Number of ears and ear length of MN 610 barley cultivar in each control and/or coexistence periods with turnip and ryegrass. UFFS, Campus Erechim/RS

Days after emergence	Number of ears [m^2]		Ear length [cm]	
	control	coexistence	control	coexistence
0	597.33 ns	334.67 ns	7.67 ns	7.89 ns
7	545.33	429.33	8.15	8.14
14	478.67	453.33	8.56	8.30
21	477.33	460.00	8.63	8.70
28	469.33	482.67	*9.18	8.09
35	560.00	457.33	*7.83	8.95
42	485.33	393.33	7.74	8.01
120	*585.33	293.33	7.42	8.74

Means preceded by asterisk (*) in the lines, differ by t test ($p < 0.05$), comparing control and coexistence periods with each other for every variable evaluated. Means followed by the same letter in the column do not differ by Tukey's test ($p < 0.05$); ns = not significant

Table 6. Mass of 1,000 grains and hectoliter weight of MN 610 barley cultivar in each control and/or coexistence period with turnip and ryegrass. UFFS, Campus Erechim/RS

Days after emergence	Mass of 1,000 grains [g]		Hectoliter weight [kh · l^{-1}]	
	control	coexistence	control	coexistence
0	38.65 ns	38.99 ns	58.32 a	58.35 ns
7	39.11	37.32	58.60 a	56.13
14	39.02	37.66	57.65 a	58.33
21	37.96	42.22	57.77 a	57.45
28	39.80	38.12	54.03 b	57.19
35	38.07	39.10	57.35 a	57.37
42	39.20	38.48	57.56 a	57.09
120	40.02	38.68	57.92 a	57.09

Means followed by the same letter in the column do not differ by Tukey's test ($p < 0.05$); ns = not significant

The coexistence of barley with the weed species, *K. scoparia, A. retroflexus, C. album* and *F. convolvulus* (Kumar and Jha 2017) or the competition of several barley cultivars with ryegrass (Paynter and Hills 2009) negatively influenced the grain yield components of this crop when adequate control was not carried out and/or at the recommended time, which corroborates our results.

However, there are just a few studies that have evaluated the interference of weeds in barley crop in Brazil, especially for the region of Alto Uruguai in Rio Grande do Sul. Identifying and understanding the competition between the crop and the main weeds, such as turnip and ryegrass, which compete with environmental resources, is important for the adoption of integrated management. The use of herbicides can be minimized, thereby improving productivity and grain quality, reducing environmental impacts and increasing producer profits (Lamego *et al.* 2013; Kumar and Jha 2017). It is also noteworthy that integrated management is an important tool to prevent the emergence of weeds resistant to various herbicides, especially when resistance is due to the overuse of herbicides.

Economic threshold level experiment

The explanatory variables of plant density, leaf area, soil cover and dry mass of the shoots of turnip, for all barley cultivars (BRS Suabia, ANA 01, BRS Korbel, BRS Manduri, BRS Cauê and BRS Greta), presented significant *F* statistic values (Table 7). In all cultivars, the rectangular hyperbola model was adjusted appropriately to the data. R^2 mean values are presented to the data as well as R^2 mean values for plant density, leaf area, soil cover and dry mass of the shoots above

Table 7. Adjustments obtained for loss of grain yield, as a function of plant density (PD), soil cover (SC), leaf area (LA) and dry mass (DM) of turnip (*Raphanus raphanistrums*) and barley cultivars, BRS Suábia, ANA 01, BRS Korbel, BRS Manduri, BRS Cauê and BRS Greta. UFFS, Campus Erechim/RS

Barley cultivars	Relative explanatory variables				
	parameters		R^2	*MSR*	*F*
	i	*a*			
Density of turnip plants					
BRS Suábia	2.32	98.72	0.78	77.22	302.32*
ANA 01	3.40	100.00	0.77	152.60	134.32*
BRS Korbel	8.49	81.86	0.67	26.81	945.50*
BRS Manduri	3.56	88.36	0.74	83.16	270.26*
BRS Cauê	5.83	95.25	0.71	64.08	463.67*
BRS Greta	2.09	87.58	0.77	190.30	88.43*
Soil cover from turnip plants					
BRS Suábia	0.09	102.30	0.64	62.34	375.41*
ANA 01	0.08	115.50	0.93	26.54	918.58*
BRS Korbel	0.51	81.33	0.76	27.26	930.07*
BRS Manduri	0.06	103.00	0.92	62.70	359.77*
BRS Cauê	0.12	102.50	0.91	25.27	1181.99*
BRS Greta	0.03	112.30	0.67	218.90	76.35*
Leaf area of turnip plants					
BRS Suábia	0.00007	111.80	0.67	192.60	105.99*
ANA 01	0.00007	119.80	0.75	137.80	149.18*
BRS Korbel	0.0003	85.40	0.60	42.92	598.18*
BRS Manduri	0.00005	104.30	0.51	211.00	104.80*
BRS Cauê	0.0002	99.10	0.62	110.30	260.44*
BRS Greta	0.00003	158.10	0.53	276.90	62.61*
Dry mass of the aerial part of turnip plants					
BRS Suábia	0.01	126.30	0.71	127.00	172.10*
ANA 01	0.01	151.40	0.65	92.68	223.79*
BRS Korbel	0.11	81.89	0.61	44.85	563.63*
BRS Manduri	0.07	169.30	0.78	86.19	260.64*
BRS Cauê	0.08	91.70	0.75	84.63	332.10*
BRS Greta	0.007	189.00	0.76	172.70	102.82*

i and *a* = losses in productivity (%) per unit of ryegrass when the value of the variable approaches zero or tends to infinity, obtained by the rectangular hyperbola model $Y = (i.X)/(1+(i/a).X$ (Cousens 1985), respectively.
R^2 = determination coefficient; *MSR* = average square of the residue
*significant at $p \leq 0.05$

0.51 and low *MSR*. These characterize a good fit of the data to the model.

Cargnelutti Filho and Storck (2007), who worked with genetic variation involving the effect of cultivars and the heritability of corn hybrids, considered R^2 values between 0.57 to 0.66 as being moderate to good, which corroborates, in part, with our results.

The results show that the estimated values for parameter *i* tended to be lower for barley cultivars BRS Suabia, ANA 01, BRS Manduri and BRS Greta than the average values of all variables evaluated – PD, LA, SC and DM (Table 7). In this same comparison, it was observed that the lowest competitiveness was verified for the cultivars BRS Korbel and BRS Cauê, which had the greatest losses in grain productivity, in relation to the others. Some studies have reported differentiation between the competition of different barley cultivars in the presence of ryegrass and/or turnip (Paynter and Hills 2009; Tironi *et al.* 2014; Pies *et al.* 2019), which is similar to the present study. The differences between barley cultivars in competition with turnip are due to distinct genetic characteristics, that is, differences in height, maturation cycle, leaf area index, root system, among others, which cause differentiation in the competition with weeds.

The lower competitiveness of BRS Korbel and BRS Cauê, than the other barley cultivars, may be related to the differences in the maturation cycle and height (Table 7). Among the morphological characteristics, plant height is most strongly related to the low development of weeds at the beginning of the cycle, due to the shading imposed by the crop, thus competing more efficiently for the light resource (Merotto Jr. *et al.* 2009). Plant height can be influenced by competition, depending on the crop and growth habits of the weeds, reducing the penetration of light in the canopy and resulting in losses in productivity (Merotto Jr. *et al.* 2009).

Comparing the cultivars, BRS Suábia, ANA 01, BRS Korbel, BRS Manduri, BRS Cauê and BRS Greta for variable plant density, based on unit loss (i), yield losses by 2.32; 3.40; 8.48; 3.56; 5.83 and 2.09% were observed, respectively (Table 7). It has also been noted that the competition imposed by different genetic material can be a potential strategy for the integrated management of weeds in current control programs (Paynter and Hills 2009; Jha *et al.* 2017).

The results demonstrate losses of 81.6 and 72.5% in grain yield of barley cultivars BRS Korbel and BRS Cauê, when comparing the average results of i parameters of these cultivars with the other cultivars for variable leaf area (Table 7). The cultivars BRS Suábia, ANA 01, BRS Manduri and BRS Greta presented the lowest productivity losses (0.00007; 0.00007; 0.00005 and 0.00003) when compared with BRS Korbel (0.0003) and BRS Cauê (0.0002). A loss of grain yield of 80 and 71.4% was also observed for the cultivars BRS Korbel and BRS Cauê, respectively, when comparing leaf area (30,000 $cm^2 \cdot m^{-2}$) of these with the average values of the other cultivars. Thus, the degree of weed competition in relation to barley is influenced by leaf area, that is, the more leaf area the weed has, the more competitive it will be in relation to the crop, by decreasing the incidence of light, caused by shading. According to Lamego *et al.* (2013) when controlling turnip and ryegrass in wheat, the crop quickly closed the space between rows and was consequently more competitive than weeds, with a higher index of leaf area, dry mass of the shoots and grain yield. The increase in the density of *Lolium rigidum* caused high damage to growth, development and, consequently, to the productivity of barley grains, especially due to the shading imposed on the crop, with the highest production of leaf area and dry mass of plants (Paynter and Hills 2009).

The results demonstrate that when 10% of soil was covered by turnip, losses in grain yields were greater than 25% in barley cultivars (Table 7). When the soil cover was 40%, almost all barley cultivars presented losses close to 80%. This high competition between the crop and turnip is partly due to the characteristics of the weed. Its high leaf area, size, length and root volume contribute to the superiority of turnip in competing with resources of the environment (water, light and nutrients). The turnip, even in low densities can cause severe losses to the crops it infests (Georgescu *et al.* 2016). Tironi *et al.* (2014) also observed this fact when they found shading to barley caused higher losses by turnip than by ryegrass, which reduces the productivity and the quality of the harvested product. The turnip developed along with the barley crop, and because it is more competitive, it showed greater growth and consequently greater soil coverage, causing reduction in barley grain productivity.

By accumulating 200 $g \cdot m^{-2}$ of dry mass, the turnip caused a reduction in barley productivity of 1.97; 1.97; 17.34; 12.93; 13.62 and 1.39%, respectively, for the cultivars BRS Suábia, ANA 01, BRS Manduri and BRS Greta (Table 7). Turnip is considered to be one of the main weeds of barley and its control with herbicides is difficult due to the scarcity of registered products or even the fact that this species is resistant to some herbicides recommended for this purpose. Forte *et al.* (2017), when evaluating the dry mass productivity of different winter coverings, in the Alto Uruguai region of Rio Grande do Sul, reported an average production of 5.0 $t \cdot ha^{-1}$ by turnip, which makes it very competitive when infesting crops. The increase in the dry mass accumulation of the species *K. scoparia, A. retroflexus, Ch. album* and *F. convolvulus* cause a proportional increase in the loss of grain yield in the barley crop, as reported by Kumar and Jha (2017).

The results for productivity losses of barley cultivars, in relation to the percentage of soil cover and dry mass of the shoots, show similarity to that observed in relation to plant density and leaf area. BRS Korbel and BRS Cauê have the greatest losses in productivity and are the least competitive (Table 7). The increase in leaf area, soil cover and dry mass of the shoots of turnip is directly related to plant density, thus explaining the similarity in the productivity losses between the variables evaluated. Among the factors linked to this interference imposed by weeds, the competition for light and nutrients (Merotto Junior *et al.* 2009; Jha *et al.* 2017) is especially important.

Parameter i is an index used to compare the relative competitiveness between species (Swanton *et al.* 2015; Galon *et al.* 2019). Different values were observed for barley cultivars; BRS Suábia, ANA 01, BRS Korbel, BRS Manduri, BRS Cauê and BRS Greta for the variables of plant density, soil cover, leaf area and dry mass of the shoots (Table 7). A comparison of cultivars, considering parameter i, in the average of the four explanatory variables (plant density, soil cover, leaf area or dry mass of the shoots), showed the following order in relation to competitiveness: BRS Greta > BRS Suábia > ANA 01

> BRS Manduri > BRS Cauê > BRS Korbel (Table 7). Possibly the difference between the cultivars is partially due to different genetic characteristics, as already explained, such as height, cycle, leaf area index, root system, plant architecture, tillering, among others. This conclusion was also found in other studies in which the authors evaluated effects of crop cultivars in the presence of different weeds (Paynter and Hills 2009; Bajwa *et al.* 2017; Galon *et al.* 2019; Pies *et al.* 2019; Tavares *et al.* 2019). It should also be noted that the differentiation existing between barley cultivars may be related to more efficient use of environmental resources, or the occurrence of high standard error in the estimation of parameter *i,* attributed to the variability associated with field experimentation and/or the crop phenotypic plasticity (Agostinetto *et al.* 2010; Galon *et al.* 2019).

Different *i* parameters from explanatory variables for the cultivars BRS Suábia, ANA 01, BRS Korbel, BRS Manduri, BRS Cauê and BRS Greta were observed. In other words, there was differentiation in the competition level between the crop and the weed, according to the cultivar involved (Table 7). It is noteworthy that cultivar BRS Greta showed the lowest loss of productivity in the mean of parameter *i* evaluated in variables of plant density, leaf area, soil cover and dry mass of the shoots. However, compared to the others, it was one of the cultivars with the lowest grain yield (903 kg · ha^{-1}).

The cultivars have different productive potentials. In this study, less productive materials had a greater capacity to compete with turnip, possibly due to the less need to allocate resources to other plant organs and not to the ear. Weed competition and their greater density in coexistence with crops is directly related to leaf production, which is responsible for intercepting solar radiation and thus negatively interfering the use of environmental resources (Merotto Jr. *et al.* 2009). According to Paynter and Hills (2009), weed competition in the barley crop depended on the cultivar and the dry mass of the weed shoots. This was reflected in the production of grains and ears, which corroborates our study.

Cultivars with the same maturation cycle showed differentiated values for parameter *i* (Table 7). This shows that the cultivars responded differently to competition with turnip. There are differences in the location of barley production, climate, soil and the management adopted. These factors have the most influence on the increase or reduction of the competitiveness of crops with weeds (Paynter and Hills 2009; Tironi *et al.* 2014.

The results demonstrate that in most situations the estimates for parameter *a* were overestimated by the model, with losses of barley grain yields greater than 100%, in at least one of the variables of plant density, soil cover, leaf area, and dry mass of the shoots (Table 7). For the variable of plant density, all cultivars had values of 100% or less than 100% for parameter *a*. The cultivar BRS Korbel showed maximum losses, also below 100% for all studied variables and BRS Cauê only for plant density, leaf area and dry mass of the shoots of turnip plants. Results greater than 100% of parameter *a* may have been because higher turnip densities were insufficient to adequately estimate the maximum loss of productivity. According to Cousens (1991), to obtain a reliable estimate for parameter *a*, it is necessary to include very high weed densities in the experiment, above those commonly found in crops. There is evidence that barley and wheat cultivars show particular behavior regarding morphological and productivity variables. This difference was also observed in the allelopathic effect with the weeds and in the density of the crops when in competition (Paynter and Hills 2009; Bajwa *et al.* 2017).

An option to prevent productivity losses from being overestimated would be to limit the maximum loss to 100%. In addition, productivity losses of more than 100% are biologically unrealistic and occur when the range of weed densities is excessively narrow and/or when the higher density values are not sufficient to produce asymptotic responses to productivity losses (Cousens 1985; Galon *et al.* 2019).

The results demonstrate that cultivar ANA 01 showed maximum losses of productivity, above 100% for all explanatory variables, except for plant density. This differed from BRS Korbel, which showed losses below 100% for all variables (Table 7). This may be due to the differences in initial growth, height, tiller production capacity, leaf size and maturation cycle, which is directly associated with the productive potential of the species (Merotto Jr. *et al.* 2009; Paynter and Hills 2009; Jha *et al.* 2017).

The comparison between the explanatory variables for all barley cultivars demonstrated a better fit to the model for the variables of soil cover > plant density > dry mass of the shoots > leaf area, considering the highest mean values of R^2 and *F*, and the lowest mean values of *MSR*. This showed that soil cover can be used to replace other variables to estimate losses in barley grain yields (Table 7). It is noteworthy that the two variables (soil cover and plant density) demonstrate the best adjustments to the rectangular hyperbola model and are easy and quick to measure. Furthermore, it is a low cost method of determining losses in barley grain yields in the field.

To carry out the simulation of the economic threshold level values – *ETL*, the explanatory variable plant density of turnip was used because it is most frequently used in experiments with this objective (Galon *et al.* 2019; Tavares *et al.* 2019). It is also noteworthy that this variable has some advantages over the others, such as ease, speed and low cost for determination (Agostinetto *et al*. 2010; Galon *et al*. 2019).

The success in the implementation of weed management systems for the barley crop may result from the determination of the density that exceeds the *ETL*. Thus, it was observed that the cultivars BRS Suábia, ANA 01, BRS Manduri and BRS Greta presented the highest *ETL* values in all simulations performed, with variations from 0.68 to 1.99 plants · m^{-2} (Fig. 4). The lowest *ETL* values were obtained with the cultivars BRS Korbel and BRS Cauê, with variations from 0.27 to 0.66 plants · m^{-2}. Turnip is one of the main weeds that infests winter crops. It is very competitive, difficult to control and thereby negatively affects the productivity and quality of the harvested grains. Tavares *et al*. (2019) found that *ETL* for weed turnip on wheat cultivars; BRS 328, BRS 177 and BRS Umbu, ranged from 0.99 to 22.07 plants · m^{-2}, which is somewhat similar to our results.

Taking the average of all cultivars and comparing the lowest grain yield with the best grain yield, there was a difference of 59% on *ETL* (Fig. 4). Thus, the higher the productive potential of barley cultivars, the lower the turnip density necessary to overcome the *ETL*, making it worthwhile to adopt weed control measures. Tavares *et al*. (2019), stated that turnip *ETL* on wheat rises as the price of the crop decreases, increasing the cost of control. Increasing the price reduces the impact of turnip control cost, having greater economic return for the producer.

The average results for cultivars BRS Suábia, ANA 01, BRS Korbel, BRS Manduri, BRS Cauê and BRS Greta, from the highest to the lowest price paid per barley bag, varied 1.39 times the *ETL* value (Fig. 4). Therefore, the lower the price paid per barley bag, the greater the turnip density required to exceed the *ETL* and thus compensate for the control method. Tavares *et al*. (2019) when evaluating the ryegrass *ETL* on wheat cultivars reported a similar result to that found in the present study.

Regarding the efficiency of chemical control with metsulfuron-methyl, it was observed that when the average efficiency (90%) was compared to the lowest (80%) or the highest (100%), there were alterations of approximately 93.62 and 88.35% on *ETL*, respectively (Fig. 4). Thus, the control level influences the *ETL*, and the higher the efficiency of the herbicide, the lower the *ETL* (a smaller number of turnip plants · m^{-2} needed to adopt control measures).

For turnip control costs in all cultivars, the minimum cost was approximately 52.34%, lower than the maximum cost. Thus, the higher the cost of the control method, the greater the ETL and more turnip plants · m^{-2} are needed to justify control measures (Fig. 4).

The use of *ETL* as a tool for weed control should be associated with good agricultural practices for barley management, since its implementation is only justified with the use of crop rotation, proper plant arrangement, more competitive cultivars, adequate sowing times, correction of soil fertility, among others (Tironi *et al*. 2014; Kumar and Jha 2017; Bajwa *et al*. 2017; Galon *et al*. 2019; Tavares *et al*. 2019).

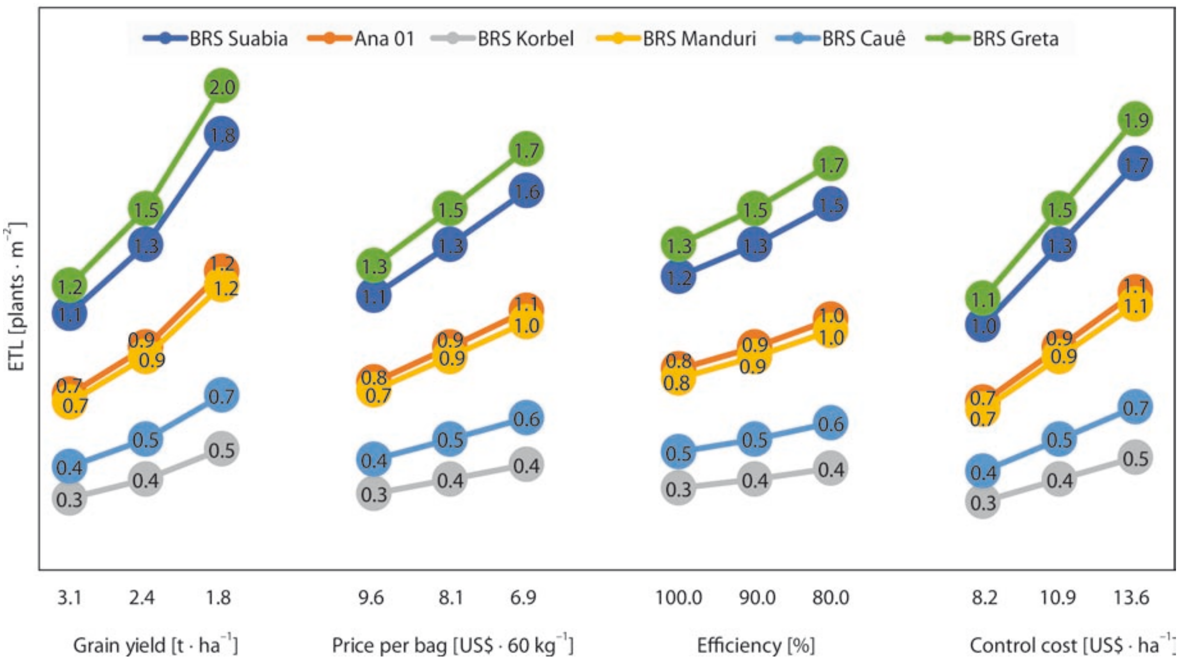

Fig. 4. Economic threshold level (*ETL*) for barley as a function of cultivars, grain yield (kg · ha^{-1}), price per bag (US$ 60 · kg^{-1}), herbicide efficiency (%), control cost (US$ · ha^{-1}) and turnip density (plants · m^{-2})

The *ETL* values varied according to the cultivar, thus it was evident that the different genetic characteristics provided differentiation in the competition with turnip. This fact is important because the producer is then able to choose the cultivar that demonstrates greater competitive ability in the presence of weeds, thereby avoiding the overuse of herbicides, causing less environmental pollution and producing healthier food.

Conclusions

The dry mass of the plants was influenced by competition between species, with significant differences at 28 DAE. The number of ears, the ear length, the number of full, sterile grains and total grains per ear, the mass of 1,000 grains and the hectoliter weight of barley were not influenced by control or coexistence periods.

The management measures for turnip and ryegrass infesting barley should be adopted between 12 and 22 days after the emergence of the crop in the Alto Uruguai region of Rio Grande do Sul. This period is known as the critical control period.

The cultivars BRS Suábia and BRS Greta were the most competitive in the presence of turnip plants · m^{-2}, while BRS Korbel and BRS Cauê showed negative aspects in the interaction with the competitor, which are not indicated for areas where this weed is present.

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