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Interference and economic damage level of alexandergrass in beans as a function of plant density

Interferência e nível de dano econômico de papuã em feijoeiro em função da densidade de plantas

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ABSTRACT

The study of bean sowing density and the level of economic damage (EDL) caused by alexandergrass (*Urochloa plantaginea*) are important tools for adequately adopting the integrated management of this weed and, thus, producing food with higher quality and less pesticide residue. Therefore, the objective of this work was to evaluate the interference and the level of the economic damage of alexandergrass in competition with the common bean, estimated as a function of sowing densities of the crop and the weed. The bean cultivar IPR Uirapuru was used. The treatments consisted of four bean densities (140,000; 180,000; 220,000 and 260,000 plants ha^{-1}, respectively) and alexandergrass that varied from 0 to the maximum of 104 plants m^{-2}. The experiment was installed in a Red Aluminoferric Latosol, at the experimental area of the Federal University of the Southern Border, campus Erechim/RS, on 10/31/2016. We used the rectangular hyperbola model to describe the relationship between the loss of bean grain yield and the explanatory variables of plant density (DP), soil cover (CS), leaf area (AF) and shoot dry matter (MS). Therefore, the variables CS and DP can be used instead of AF and MS to estimate grain yield losses in common beans. The density of 260,000 plants ha^{-1} of bean showed greater competitiveness with alexandergrass and the highest values of EDLs, justifying the adoption of weed control management at higher densities.

KEYWORDS: *Phaseolus vulgaris*, *Urochloa plantaginea*, competitive interaction.

RESUMO

O estudo da densidade de semeadura do feijoeiro e do nível de dano econômico (NDE) ocasionado pelo papuã (*Urochloa plantaginea*) são ferramentas importantes para a adoção do manejo integrado dessa planta daninha e, assim, produzir um alimento com maior qualidade e menor resíduo de agrotóxico. Diante disso, objetivou-se com o trabalho avaliar a interferência e o nível de dano econômico do papuã em competição com o feijoeiro, estimados em função de densidades de semeadura da cultura e da planta daninha. Os tratamentos foram compostos por densidades do feijoeiro, cultivar IPR Uirapuru (140.000, 180.000, 220.000 e 260.000 plantas ha^{-1}) e do papuã que variaram de 0 até o máximo de 104 plantas m^{-2}. O experimento foi implantado em um Latossolo Vermelho Aluminoférrico típico na área experimental da Universidade Federal da Fronteira Sul, campus Erechim/RS, em 31/10/2016. Para descrever a relação entre a perda de produtividade de grãos do feijoeiro e as variáveis explicativas; densidade de plantas (DP), cobertura do solo (CS), área foliar (AF) e massa seca da parte aérea (MS), usou-se o modelo da hipérbole retangular. As variáveis CS e DP podem ser usadas em substituição a AF e a MS para estimar as perdas de produtividades de grãos do foeijoeiro. A densidade de 260.000 plantas ha^{-1} do feijoeiro apresentou maior competitividade com o papuã e os maiores valores de NDEs, justificando a adoção de medidas de controle da planta daninha em densidades mais elevadas.

PALAVRAS-CHAVE: *Phaseolus vulgaris*, *Urochloa plantaginea*, interação competitiva.

INTRODUCTION

The average yield of beans (*Phaseolus vulgaris*) in Brazil in the 2020/21 crop year was 984 kg ha^{-1} (CONAB 2022), which is very low when compared to crops that adopt high technologies. Many factors negatively affect the bean plant and cause a drop in productivity, especially the interference caused by weeds (KALSING & VIDAL 2013, VIECELLI et al. 2021).

Among the environmental conditions the competition with weeds can cause more than 71% reductions in grain yield (PARREIRA et al. 2014, GALON et al. 2016) when not properly controlled and in the critical period of competition, which goes from 24 to 50 days after emergence (FRANCESCHETTI et al. 2019).

Bean has low competitiveness because of its short cycle, C3 metabolism slowly first growth, and superficial root system, which make the crop suffer from competition for water, light, and nutrients when infested by weeds, which in most situations show greater competitiveness than crops (MANABE et al. 2015, FRANCESCHETTI et al. 2019).

One of the most damaging weeds in the bean crop is alexandergrass (*Urochloa plantaginea*), which appears in the middle of many crops in various locations in Brazil, causing severe damage to the productivity and profitability of crops (KALSING & VIDAL 2013, TAVARES et al. 2013, FRANCESCHETTI et al. 2019). Alexandergrass belongs to the Poaceae family with C4 metabolism and has a high competitiveness capacity when it infects the bean plant since it presents a rapid growth and development, as well as the ability to infect large extensions of land, consequently causing site domination and shading of the crop (KALSING & VIDAL 2013, TAVARES et al. 2013, FRANCESCHETTI et al. 2019).

Factors such as spacing and population density can affect weed emergence and the productivity of the bean crop. For example, a modification in row spacing or plant density will alter the spatial arrangement of plants in the area, or selecting genotypes that present specific morphophysiological characteristics, such as high stature and rapid initial plant growth, can increase competitiveness with weeds (BEZERRA et al. 2014, FONTES et al. 2015, LEQUIA et al. 2021).

The best plant arrangement, i.e., with changes in spacing and density of the bean plant, can favor the control of weeds in the crop (FONTES et al. 2015, SORATTO et al. 2017). In addition, in agricultural environments where water availability and nutrients are not limited, solar radiation will be the resource that determines the growth of crops and weeds (FONTES et al. 2015).

The densification or modification of the spatial arrangement of crop plants promotes changes in the quantity and quality of light and also modifies the soil temperature below the crop canopy, affecting seed germination and weed growth (FONTES et al. 2015, PARADISO & PROIETTI 2021).

The control of alexandergrass weeds in the bean is almost exclusively carried out using herbicides due to their practicality, efficiency, and lower cost compared to other control methods (VIECELLI et al. 2021). However, the search is currently on for more sustainable production models to have a less environmental impact on the agro-ecosystems, fewer residues in food, and reduced poisoning when applying herbicides in crops.

The application of herbicides based on the concept of the level of economic damage (EDL) provides for the adoption of the control method only when the damage caused by the weeds is greater than the cost of the control method (KALSING & VIDAL 2013, GALON et al. 2016, BRANDLER et al. 2021). When using EDL to make crop weed control decisions, the crop's estimated grain yield losses are compared to the costs of the available control options, allowing an analysis of the gain obtained with the control treatment used (KALSING & VIDAL 2013, GALON et al. 2016).

To estimate EDL regression equations or damage functions are usually adopted, they relate crop yield losses to possible weed control measures at the time of post-emergence control (KALSING & VIDAL 2013, GALON et al. 2016, BRANDLER et al. 2021).

Among the various factors that affect competition between weeds and crops are those associated with the soil, climate, and management practices. Management practices such as cultivars with higher competitive ability, soil fertility correction, higher sowing density, among others, can reduce the degree of weed competition, increasing the EDL and minimizing the need to adopt control measures (KALSING & VIDAL 2013, PARREIRA et al. 2014, GALON et al. 2016, BRANDLER et al. 2021).

When this information is available, it can play a significant role in changing the management method that relies mainly upon herbicides to a system based on ecophysiological knowledge (KALSING & VIDAL 2013, PARREIRA et al. 2014, GALON et al. 2016, BRANDLER et al. 2021) and thus has a more sustainable model of weed control.

Among the many tools available to study plant competition in a community is the non-linear rectangular hyperbola equation. This model relates crop yield loss using the variables weed density, aboveground dry mass, ground cover, and leaf area (KALSING & VIDAL 2013, GALON et al. 2016, BRANDLER et al. 2021). In addition, the hyperbola model contains parameters (i and a) that have biological and agronomic significance, used as indices of competitiveness (COUSENS 1985).

The variation in the grain yield losses of the bean crop due to alexandergrass interference and according to the sowing density of the crop or weed can be measured by mathematical models that allow establishing levels of economic damage. Therefore, the study's objective was to evaluate the interference and the level of the economic damage of alexandergrass in competition with black beans, estimated as a function of crop and weed sowing densities.

MATERIAL AND METHODS

The experiments were conducted in the experimental area of the Universidade Federal da Fronteira Sul (UFFS), Campus Erechim/RS, on 10/31/2016 in the geographic coordinates 27º43'47 "S latitude and 52º17'37 "W longitude and altitude of 670 m and the soil categorized as typical Red Aluminoferric Latosol (SANTOS et al. 2018).

The pH correction and soil fertilization were performed according to the physical-chemical analysis and following the technical recommendations for the bean crop (CQFS-RS/SC 2016). The chemical and physical characteristics of the soil were: pH in water 4.8; MO= 3.5%; P= 4.0 mg dm^{-3}; K= 117.0 mg dm^{-3}; Al^{3+}=0.6 cmolc dm^{-3}; Ca^{2+}= 4.7 cmolc dm^{-3}; Mg^{2+}= 1.8 cmolc dm^{-3}; CTC(t)= 7,4 cmolc dm^{-3}; CTC(TpH=7,0)= 16,5 cmolc dm^{-3}; H+Al= 9,7 cmolc dm^{-3}; SB= 6,8 cmolc dm^{-3}; V= 41% and Clay= 60%. The soil sample was collected at a depth of 0 to 20 cm using a cutting spade. The organic matter (MO) content was determined by the Walkley-Black method, extractable P by Mehlich-1, pH in water in soil: water 1:1 solution and K, Ca, Mg and Al according to TEDESCO et al. (1995).

The adopted cultivation method was the no-tillage system in the straw formed by black oat + vetch (4 t ha^{-1} of dry mass), dissected with glyphosate (1,080 kg ha^{-1} acid equivalent) 15 days before sowing. The experimental design used was a randomized block design, and the treatments consisted of densities of black type bean cultivar IPR Uirapuru in competition with the respective crop densities (Table 1).

Table 1. The density of bean plants (ha^{-1}) and alexandergrass (m^{-2}) at the experiment. UFFS, Erechim/RS, 2016/17.

Bean density (ha^{-1})	Alexandergrass density (m^{-2})
140,000	0, 6, 16, 24, 34, 50, 52, 54, 84 e 84
180,000	0, 6, 8, 8, 20, 22, 28, 30, 40 e 96
220,000	0, 4, 4, 34, 40, 44, 48, 56, 58 e 74
260,000	0, 2, 4, 10, 26, 34, 36, 56, 64 e 104

Because alexandergrass comes from the soil seed bank, the establishment of densities was variable because factors such as infestation, vigor, dormancy, humidity, predator attack, among others, prevent the establishment of the same number of plants per area (experimental unit). Weed densities were established from the soil seed bank by applying the herbicide fluazifop-p-butyl (0.1875 kg ha^{-1}) when the crop was at the V3 stage (3 trifoliolate) and the weed was at the two-leaf to one tiller stag. The season chosen is the most appropriate for post-emergence herbicide application in the bean crop. The alexandergrass plants studied were protected with plastic cups and buckets to prevent them from being injured by the herbicide.

The fluazifop-p-butyl herbicide was applied using a CO_2 pressurized precision knapsack sprayer equipped with four DG 110.02 fan spray tips, maintaining a constant pressure of 210 kPa and a travel speed of 3.6 km h^{-1}, which provided a flow rate of 150 L ha^{-1} of herbicide solution.

Each experimental unit (plot) was composed of a 15 m^2 area (3 x 5 m), and the sowing consisted of 6 lines, 5 m long and spaced at 0.50 m apart. The sowing density of the bean plant was set according to the proposed treatments. For base fertilization: was used 250 kg ha^{-1} of the formula 02-20-20 (N-P_2O_5-K_2O) and in top dressing 50 kg ha^{-1} of nitrogen in the form of urea (45% N) was applied when the bean was in the V3 to V4 stage, according to the chemical analysis of the soil and the expected grain yield of the crop to 3.0 t ha^{-1}. All other management practices used were those recommended by research for the black-type bean crop.

Quantification of plant density (PD), leaf area (LA), ground cover (CS), or dry mass of the upper part (MS) of alexandergrass was performed 30 days after the emergence (DAE) of the crop. For the determination of the DP variable, the plants were counted in two areas of 0.25 m^2 (0.5 m x 0.5 m) per plot. The SC by alexandergrass plants was evaluated visually, individually by two evaluators, using a percentage scale in which zero and 100 correspond to the absence and total coverage of the soil, respectively. The quantification of the AF of the competing plant was performed with a portable electronic AF integrator, model CI-203, brand CID Bio-Science, measuring all plants in an area of 0.25 m^2 per plot. After AF determination, the plants were packed in Kraft paper bags and placed in a forced air circulation oven at a temperature of 60±5 ºC until reaching constant mass to determine the MS.

The quantification of bean grain yield was obtained by harvesting the plants in a 6 m^2 useable area of each experimental unit when the moisture content of the grains reached approximately 18%. After grain weighing the humidity was determined and the masses were standardized at 13%. With the grain yield data, the percentage of losses in comparison to the plots kept without infestation (controls) were calculated, according to Equation 1:

$$\text{Loss (\%)} = \left(\frac{\text{Ra} - \text{Rb}}{\text{Ra}} \right) x\,100 \qquad \text{Equation 1}$$

Where: Ra and Rb: crop yield without or with the presence of the competing plant, alexandergrass, respectively.

Before data analysis, the CS (%), AF (cm^2), or DM (g m^{-2}) values were multiplied by 100, thus dispensing with the use of the correction factor in the model (GALON et al. 2016, BRANDLER et al. 2021).

The relationships between percentage losses in bean yield as a function of the explanatory variables were calculated separately for each crop sowing density, using the non-linear regression model derived from the rectangular hyperbola, proposed by COUSENS (1985), according to Equation 2:

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

Where: Pp = yield loss (%); X = DP, CS, AF, and MS; i and a = yield losses (%) per unit of alexandergrass plants when the variable value approaches zero and, it tends to infinity, respectively.

For the calculation procedure, the method of Gauss-Newton was applied, which, by successive iterations, estimates parameter values at which the sum of squares of the deviations of the observations from the fitted values is minimal, as described by BRANDLER et al. (2021). The value of the F statistic ($p \leq 0.05$) provided as a criterion for analyzing the data to the model. Acceptance criteria for fitting the data to the model based on the significance of F, the highest value of the coefficient of determination (R^2), and the smallest value of the mean square of the residual (QMR).

To calculate the level of economic damage (EDL), the estimates of parameter i obtained from Equation 2 (COUSENS 1985) and the Equation adapted from LINDQUIST & KROPFF (1996) - Equation 3 - were used:

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

Where: EDL = economic damage level (plants m^{-2}); Cc = control cost (herbicide and terrestrial tractor application, in dollars ha^{-1}); R = black bean yield (kg ha^{-1}); P = black bean price (dollars kg^{-1} grain); i = loss (%) of black bean yield per unit of competing plant when the population level approaches zero and H = herbicide efficiency level (%).

Thus, for the control cost (Cc), the average price of \$ 36.81 ha^{-1} (400 g ha^{-1} ammonium glufosinate + adjuvant) was considered, with the maximum and minimum cost changed by 25% compared to the average cost.

The bean yield (R) and the product price (P) were based on the lowest, average, and highest obtained in the Rio Grande do Sul in the last ten (10) years. The herbicide efficiency (H) values were in order of 80, 90, and 100% control, with 80% being the minimum control considered efficacious for the weed (SBCPD 1995). For the EDL simulations, intermediate values were used for the variables not being calculated.

RESULTS AND DISCUSSION

For the variables DP, AF, CS, and MS of alexandergrass, significance was observed for all densities at which crop and weed coexisted in the plant community (Table 2). At all bean densities (140,000; 180,000; 220,000 and 260,000 plants ha^{-1}), the rectangular hyperbola model fitted the data adequately, presenting R^2 values higher than 0.58 and low QMR, which characterizes a good fit of the data to the model. GALON et al. (2016) also observed adequate fit to the rectangular hyperbola model when testing the black type bean cultivars (IPR Uirapuru, BRS Supremo, BRS Campeiro, Fepagro 26, BRS Esplendor e IPR Tuiuiú) in competition with different densities of black prickly pear (Bidens Pilosa) similar to the data observed in this study. The effects of cultivars and heritability of corn hybrids CARGNELUTTI FILHO & STORCK (2007) are considered moderate to good R^2 values between 0.57 and 0.66.

The results show that the estimated values for the parameter i tended to be lower for the bean density of 260,000 plants ha^{-1} compared with all the evaluated characteristics - DP, AF, CS, and MS (Table 2). In the same comparison, the lowest competitiveness was obtained for the densities of 140,000, 180,000, and 220,000 plants ha^{-1}, presenting the highest grain yield losses relative to the other densities.

Table 2. Adjustments obtained with Cousens' rectangular hyperbola model (1985) for grain yield loss with alexandergrass (*Urochloa plantaginea*) interference as a function of bean sowing densities: 140,000; 180,000; 220,000 and 260,000 plants ha^{-1} in response to relative explanatory variables. UFFS, Erechim/RS, 2016/17.

Bean densities (plants ha^{-1})	Parameters[1]		R^2	QMR	F
	i	*a*			
	Relative plant density of alexandergrass				
140,000	5.01	107.00	0.75	125.20	167.49*
180,000	5.62	155.20	0.85	405.50	27.75*
220,000	9.11	90.99	0.74	177.60	115.99*
260,000	4.55	122.90	0.95	209,30	97.09*
Bean densities (plants ha^{-1})	Relative ground coverage of alexandergrass				
140,000	0.08	95.28	0.74	121.00	173.52*
180,000	1.64	387.40	0.59	178.30	68.30*
220,000	0.06	110.40	0.77	117.30	178.09*
260,000	0.04	131.00	0.88	75.43	275.45
Bean densities (plants ha^{-1})	Relative leaf area of alexandergrass plants				
140,000	0.0006	96.30	0.58	179.00	115.98*
180,000	0.0200	236.60	0.94	98.24	116.12*
220,000	0.0020	76.13	0.58	483,20	37.16*
260,000	0.0004	120.90	0.81	215.40	94,24*
Bean densities (plants ha^{-1})	Relative aboveground dry mass of alexandergrass plants				
140,000	0.06	104.20	0.85	160.50	128.50*
180,000	1.21	480.70	0.94	170.50	72.15*
220,000	4.75	94.86	0.58	422.40	34.09*
260,000	0.05	112.40	0.87	197.30	79.59*

[1]*i* and *a*: bean grain yield losses (%) per unit of Alexander grass plants when the variable value approaches zero or tends to infinity, respectively; * Significant at p≤0.05.

Increasing the string bean sowing density from 41,666 to 166,666 plants ha^{-1} increased the percentage of light intercepted by 50%, increased leaf area index growth by 206%, and crop growth rate by 130% (MENDES et al. 2005). In addition, the increase in sowing density of carioca-type bean reduced weed infestation, mainly by increased shading, raising competition for light (DUSABUMUREMYI et al. 2014). This fact demonstrates that the bean can present greater interspecific competition when sown at high densities by taking advantage more efficiently of the resources in the environment and thus gaining a competitive advantage over the weeds that may infest the crop, especially related to light.

Considering that alexandergrass is a plant with C4 metabolism and needs a high quantity of light, in this case, this resource may have been more limited than the others, such as water and nutrients, for its growth and development at the highest density (260,000 plants ha^{-1}) and thus the crop demonstrated greater competitiveness at this density. According to PARADISO & PROIETTI (2021), light quantity (intensity and photoperiod) and quality (spectral composition) affect plant growth and physiology and interact with other environmental parameters and crop factors in determining the behavior, especially of crop plants.

According to PARADISO & PROIETTI (2021), the light dictates specific signals that regulate the development, formation, and metabolism of plants, in the complex phenomenon of photomorphogenesis, more than supplying the energy for photosynthesis. DUSABUMUREMYI et al. (2014) observed positive responses regarding bean grain yields with increasing sowing density because the crop tended to dominate the environment over the weed infesting. The results observed by LEQUIA et al. (2021) describe how weed biomass (*Chenopodium album*, *Amaranthus retroflexus*, *Solanum physalifolium* and *Setaria viridis*) was reduced by 6 kg ha^{-1} for each increase of 1000 seeds ha^{-1} in the sowing of carioca type bean. Increasing the sowing density gives the bean a higher ability to compete with weeds, resulting in reduced grain yield losses, as was the case in this study.

When comparing the bean planting densities for the characteristic DP, based on unit loss (i), yield losses of 5.01, 5.62, 9.11, and 4.55% were observed for densities of 140,000, 180,000, 220,000, and 260,000 plants ha^{-1}, respectively (Table 1). According to FONTES et al. (2015), increases the plant density of caupi-bean cultivar, BRS Guariba from 89 to 222 thousand plants ha^{-1}, decreases weed dry mass accumulation by about 60%. Similarly, the values of weed dry mass when comparing the lowest sowing density (111 thousand plants ha^{-1}) and the highest density (200 thousand plants ha^{-1}) of the cowpea cultivars, Caldeirão and BRS Novaera, occurred 76 and 86% reduction in weed growth, respectively (FONTES et al. 2015).

The results show that a density of 80 plants m^{-2} of alexandergrass in competition with the bean at densities of 140,000, 180,000, 220,000 and 260,000 plants ha^{-1}, caused losses in grain yield of 84.45, 89.17, 80.89 and 91.88%, respectively. Regardless of the sowing density of the bean plants when in competition with 80 plants m^{-2} of alexandergrass, there was an average loss of grain yield of 92.80% (Table 2). When comparing the losses of grain yields caused by an infestation of one against 80 plants m^{-2} of alexandergrass, in the average of all sowing densities (140,000, 180,000, 220,000 and 260,000 plants ha^{-1}) there was an increase to 20 times. Knowing that alexandergrass is a companion weed to summer crops grown in southern Brazil (KALSING & VIDAL 2013), which appears at high densities and that densities exceeding 80 plants m^{-2} are easily obtained (FRANCESCHETTI et al. 2019), it is clear that its management becomes crucial to avoid high grain yield losses of the bean plant.

The study showed an average loss of 40.45% in the grain yield of the bean plant considering all densities for the AF characteristic of the alexandergrass (14000 cm^2 m^{-2}), with the highest losses occurring at densities of 180,000 and 220,000 plants ha^{-1} with 128.24 and 20.47%, respectively (Table 1). When analyzing the bean plant relative to the smallest AF of the alexandergrass (2000 cm^2 m^{-2}) compared to the largest AF (14000 cm^2 m^{-2}), it becomes apparent that at densities of 180,000 and 220,000 plants ha^{-1}, the highest losses occurred. Therefore, the degree of weed competition relative to the bean plant is influenced by the AF, i.e., the more AF the alexandergrass has, the most competitive it will be compared to the crop due to the shading it will impose on the crop. GALON et al. (2018) also observed that when alexandergrass appeared in a higher proportion of plants than sweet sorghum the weed showed more AF than the crop and consequently competitiveness ability.

The results for yield loss of the bean densities relative to the percentage of CS demonstrate the same trends as those observed for DP and AF (Table 2). Bean seeded at densities of 140,000, 180,000 and 220,000 plants ha^{-1} showed the highest reductions in grain yields when the soil was 20% alexandergrass cover. At 80% CS of alexandergrass, similar results were observed when it showed up at 20% for the same three-bean densities (140,000, 180,000, and 220,000 plants ha^{-1}). There was an average increase in grain yield losses of more than 69% with a 60% increase in soil coverage by alexandergrass, i.e., for each 1% increase in CS, there was a loss of 1.15% in bean yields, showing that this weed is very competitive when infesting the crop. GALON et al. (2016) also reported that increased CS by black prickly pear caused increases in grain yield losses of six black-type bean cultivars.

By accumulating 75 g m^{-2} of dry mass, alexandergrass caused the highest yield reductions of 76 and 74% for sowing densities of 180,000 and 220,000 plants ha^{-1}, respectively (Table 2). This result correlates with those found for DP, AF, and CS, where the highest grain yield losses of the bean were observed at these same two densities. MANABE et al. (2015), when evaluating the competition of bean with weed species, also found reductions in the accumulation of a total dry mass of the crop when it coexisted with *Urochloa plantaginea* (alexandergrass), which supports the results found in this study.

The parameter *i* is an index used to compare the relative competitiveness between species

(SWINTON et al. 1994) and showed differentiated values for bean densities in the explanatory variables tested (Table 2). The comparison between bean densities considering the parameter *i*, on the average of the four explanatory variables (DP, CS, AF, or MS), showed that the order of placement relative to competitiveness was: 260,000 > 140,000 > 180,000 > 220,000 plants ha^{-1} (Table 2).

The differences observed between the results of the bean densities are due to the optimal use of space or the availability of environmental resources, or to the occurrence of a high standard error in the estimation of the parameter *i*, attributed to the variability associated with field experimentation and/or the phenotypic plasticity of the crop as reported for soy plants (BALBINOT JUNIOR et al. 2018). Sowing annual crops at higher plant densities causes the plant canopy to close more quickly due to the larger leaf area, resulting in shading of the soil surface, alteration in the quantity and quality of photosynthetically active radiation below the crop canopy, and this will negatively affect weed growth (BEZERRA et al. 2014, WU et al. 2021).

The estimates of parameter *a* in the vast majority independently of the explanatory variable were higher than 100%, i.e., overestimated by the model (Table 2). The PD, AF, and MS at the density of 220,000 plants ha^{-1} of the bean showed values lower than 100%, just as for the CS and AF when the crop appeared with 140,000 plants ha^{-1}. Losses exceeding 100% can occur when the higher weed densities are insufficient to adequately estimate the maximum grain yield loss of the crop (COUSENS 1985).

To obtain a reliable estimate of parameter *a*, it is necessary to take the weed density range to very high levels in the experiment, above those commonly found under field conditions (COUSENS 1985). Losses exceeding 100% for parameter a were also observed by BRANDLER et al. (2021) when studying turnip-infested canola competition subjected to different management methods, which corroborates in parts the results observed in the present study.

An alternative to avoid overestimating yield losses would be to limit the maximum loss to 100%. However, the limitation will influence the estimation of parameter *i* and may result in lower predictability of the rectangular hyperbola model (KALSIN & VIDAL 2013, BRANDLER et al. 2021). In addition, yield losses exceeding 100% are biologically unrealistic and occur when the range of weed densities is too narrow and/or when higher density values are insufficient to produce an asymptotic yield loss response (BRANDLER et al. 2021).

When the estimates of parameter *a* are less than 100% it becomes possible to properly simulate the maximum grain yield losses of crops when infested by weeds (KALSIN & VIDAL 2013, GALON et al. 2016). The higher the productive potential of crops and if soil fertility, water availability, and light conditions are adequate, the lower the daily percentage loss caused by a particular weed species (KALSING & VIDAL 2013).

Densities (140,000, 180,000, 220,000, and 260,000 plants ha^{-1}), in general, showed a better fit to the model for the variables CS > DP > MS > AF, considering the highest mean values of R^2 and F, and the lowest mean values of QMR (Table 2). This aspect evidences that CS is suitable to be used in place of the other variables to estimate the grain yield losses of the bean plant. It is noteworthy that the two variables (CS and DP) showed the best fits to the rectangular hyperbola model are easy and quick to be determined, besides presenting a low cost of measuring the grain yield losses of the bean plant in the field.

To simulate the values of the level of economic damage - EDL, the explanatory variable DP of bean was used considering that it is the most used in experiments with this objective (KALSING & VIDAL 2013, GALON et al. 2016, BRANDLER et al. 2021). Furthermore, this variable has some advantages over the others, such as ease, speed, greater precision, and low cost for the determination (KALSING & VIDAL 2013, GALON et al. 2016).

Success in implementing management systems for alexandergrass weeds in the bean crop may stem from determining the density that exceeds the EDL. Thus, it is evident that the density of 260,000 plants ha^{-1} of bean showed the highest EDL values in all simulations performed, with variations from 0.50 to 1.23 plants m^{-2} (Figures 1, 2, 3, and 4). The density of 220,000 plants ha^{-1} showed the lowest EDL values, and between the highest and lowest EDL values were the densities of 140,000 and 180,000 plants ha^{-1}, with variations from 0.41 to 1.12 plants m^{-2}.

In the average of all bean densities and comparing the lowest with the highest grain yield, a difference in EDL amounting to 18.33% was observed (Figure 1). Therefore, the higher the yield potential of the bean densities, the lower the density of alexandergrass plants needed to overcome the EDL, making it worthwhile to adopt weed control measures.

VIDAL et al. (2010) found that the EDL of alexandergrass and morning glory when infesting the bean cultivars, IPR Graúna (black group) and UFT-06 (carioca group), rises as the price of the crop decreases, increasing the cost of control. In addition, the authors report that the increase in bean prices reduces the impact of the cost of weed control on the economic return of the crop.

The average result of all densities evaluated, from the highest versus the lowest price paid per bean bag, showed a 2.4 times variation in the EDL value (Figure 2). The lower the price paid per bag of beans, the higher the density of alexandergrass needed to exceed the EDL and thus compensate for the control method. GALON et al. (2016), when evaluating the EDL of black prickly pear on six cultivars of a black-type bean, also found similar results to those observed in the present study.

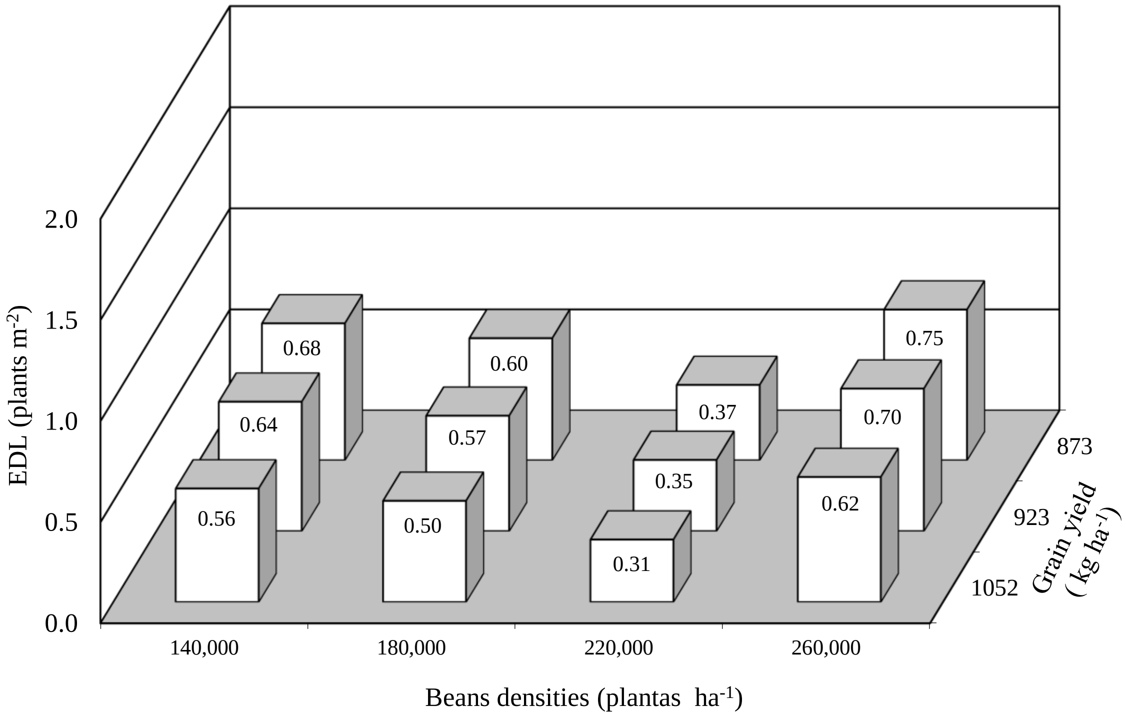

Figure 1. Economic damage level (EDL) for the common bean as a function of grain yield, alexandergrass (m^{-2}), and black beans densities (ha^{-1}). UFFS, Erechim/RS, 2016/17.

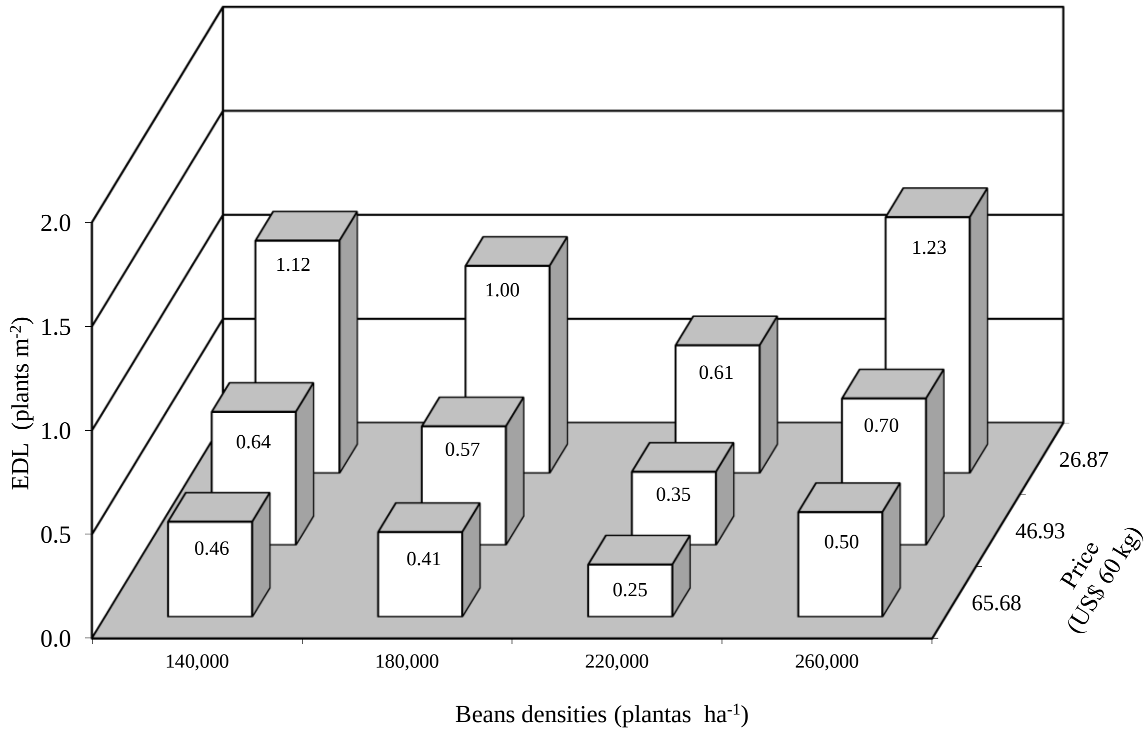

Figure 2. Economic damage level (EDL) for the common bean as a function of common bean price, alexandergrass (m^{-2}), and black beans densities (ha^{-1}). UFFS, Erechim/RS, 2016/17.

The efficiency of the chemical control method with the use of herbicide, the medium efficiency (90%), when compared with the lowest (80%) or the highest (100%), showed changes in EDL of approximately 11 and 10%, respectively (Figure 3). The level of control influences the EDL, and the higher the herbicide efficiency, the lower the EDL (lower number of alexandergrass plants m^{-2} needed to adopt control measures). These results corroborate those observed for bean competition with alexandergrass (KALSING & VIDAL 2013) and/or with beggartick (GALON et al. 2016).

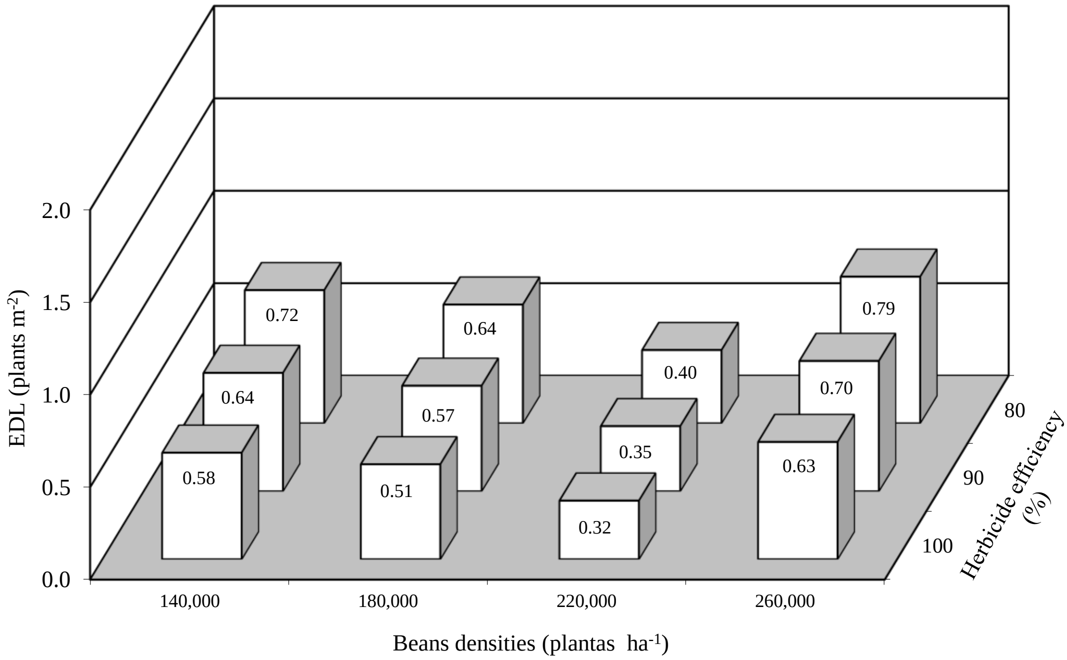

Figure 3. Economic damage level (EDL) for the common bean as a function of herbicide efficiency, and alexandergrass (m^{-2}) and black beans densities (ha^{-1}). UFFS, Erechim/RS, 2016/17.

Regarding the cost of controlling alexandergrass at all densities, it showed that the minimum charge was 40% lower when compared to the maximum rate. Accordingly, the higher the cost of the control method, the higher the EDL, and the more alexandergrass plants m-2 are needed to justify control measures (Figure 4). The same EDL performance of alexandergrass compared to bean was also observed by VIDAL et al. (2010) and GALON et al. (2016) when working with the cost of weed control of different bean cultivars.

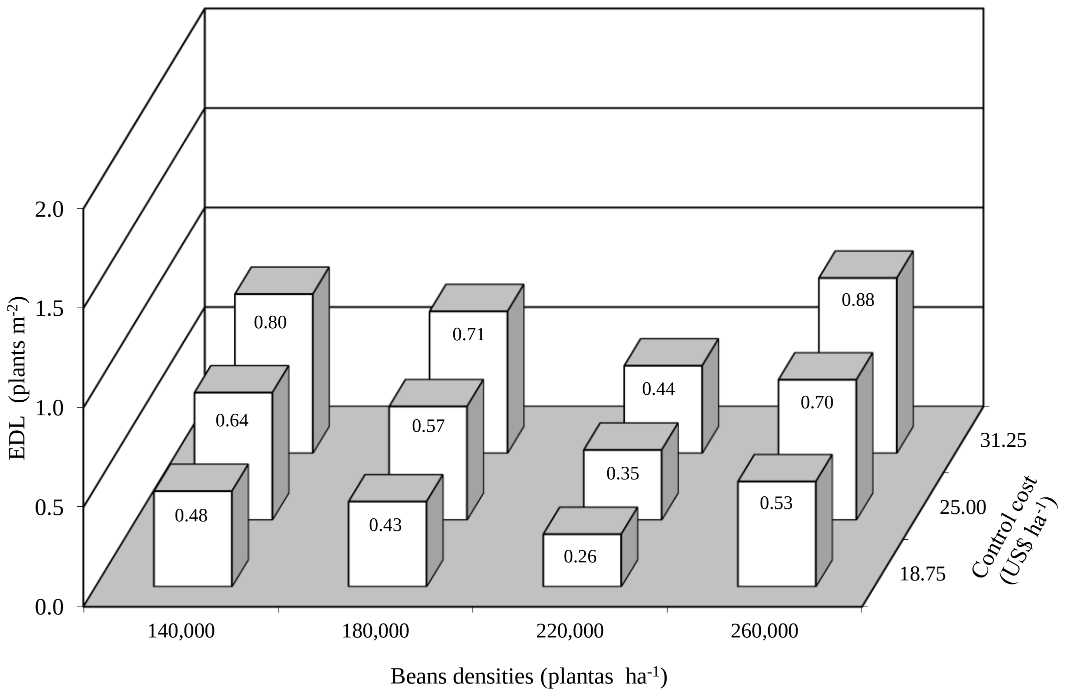

Figure 4. Economic damage level (EDL) for the common bean as a function of control cost, alexandergrass (m^{-2}), and black beans densities (ha^{-1}). UFFS, Erechim/RS, 2016/17.

The use of EDL as a weed control tool must be associated with good agricultural practices adopted from bean sowing to harvesting since its implementation is only justified in crops that use: crop rotation, adequate plant arrangement, use of more competitive cultivars, optimal sowing times, soil fertility correction, among others.

CONCLUSION

Sowing 260,000 plants ha^{-1} of bean shows greater competitiveness with alexandergrass relative to densities of 140,000, 180,000, and 220,000 plants ha^{-1}.

The EDL values ranged from 0.25 to 1.12 plants m^{-2} for densities of 140,000, 180,000, and 220,000 plants ha^{-1} of the bean, which showed less competitiveness with alexandergrass.

The highest EDL values ranged from 0.50 to 1.23 plants m^{-2} for the density of 260,000 plants ha^{-1}, which showed a higher competitiveness with alexandergrass.

The EDL decreases with the increase in grain yield, the price of the bean bag, the efficiency of the herbicide, and the reduction in the cost of alexandergrass control, justifying the adoption of control measures at lower densities of the weed.

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