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Article

Interference and Level of Economic Damage of Alexandergrass on Corn

Competitividade e Nível de Dano Econômico de Papuã em Função de Densidades de Milho

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ABSTRACT - The objective of this work was to evaluate the interference and to determine the level of economic damage (NDE) of the weed when infesting the corn crop. Treatments were composed by corn densities (2.60, 3.10, 3.65, 4.00 and 4.80 plants m^{-1}) and 10 Alexandergrass populations for each crop seeding density. The population of plants, leaf area, soil cover and shoot dry mass of Alexandergrass were evaluated as indicator of infestation. Shoot dry mass of Alexandergrass presents better adjustment to the model of rectangular hyperbole, and losses of grain yield due to interference of the weed were satisfactorily estimated by this model. Corn sowing densities of 2.60; 3.10 and 3.65 plants m^{-1} in average, were more competitive of all evaluated variables in the presence of Alexandergrass. Corn densities of 2.60; 3.10 and 3.65 plants m^{-1} increase the level of economic damage, justifying the adoption of control measures of Alexandergrass when in higher populations. NDE values ranged from 1.58 to 9.37 plants m^{-2} at the densities of 4.00 and 4.80 maize plants m^{-1}, which were less competitive with Alexandergrass.

Keywords: *Urochloa plantaginea*, *Zea mays*, competitive ability.

RESUMO - O objetivo deste trabalho foi avaliar a competitividade e determinar o nível de dano econômico de papuã infestante da cultura do milho. Os tratamentos foram compostos por densidades de milho (2,60; 3,10; 3,65; 4,00; e 4,80 plantas m^{-1}) e dez populações de papuã para cada densidade de semeadura da cultura. Como indicadores de infestação, avaliou-se a população de plantas, área foliar, cobertura de solo e massa seca da parte aérea de papuã. A massa seca da parte aérea do papuã apresentou melhor ajuste ao modelo da hipérbole retangular e às perdas de produtividade de grãos, devido à interferência da planta daninha estimada satisfatoriamente por esse modelo. A semeadura das densidades de milho de 2,60; 3,10 e 3,65 plantas m^{-1} de todas as características avaliadas foram mais competitivas do que as demais na presença do papuã. A semeadura das densidades de 2,60, 3,10 e 3,65 plantas m^{-1} aumentou o nível de dano econômico, justificando a adoção de medidas de controle do papuã nas populações mais elevadas. Os valores de NDE variaram de 1,58 a 9,37 plantas m^{-2} para as densidades de 4,00 e 4,80 plantas m^{-1} de milho, as quais foram menos competitivas com o papuã.

Palavras-chave: *Urochloa plantaginea*, *Zea mays*, habilidade competitiva.

INTRODUCTION

Corn (*Zea mays* L.) is one of the most cultivated cereals in the world and one of the main crops that make up the Brazilian trade balance (CONAB, 2018).

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Currently, Brazil is the third largest world producer, with an area of approximately 15.2 million hectares cultivated and total production of about 99.85 million tons (USDA, 2018).

Maize yield and agronomic performance may be compromised by several factors. Among them, we highlight the initial competition with weeds, which, when not controlled, cause direct interference in maize development. Weeds compete for light, water and nutrients, which are essential resources for crops of economic interest, thus reducing their availability and, consequently, grain yield (Vidal et al., 2004).

The interference of weeds in corn causes reduction in its growth and development, in addition to grain yield, and may make farming economically unfeasible (Balbinot et al., 2009). Among the weeds that infest corn, we highlight Alexandergrass (*Urochloa plantaginea*), which is present in various tropical and subtropical regions in the world. It is a noxious weed in the United States, Brazil, Paraguay, Argentina and other countries (ARS, 2018).

When not controlled, Alexandergrass can cause grain yield reduction in maize crops of up to 90% (Vidal et al., 2004). Under cultivation conditions of southern Brazil, it is one of the main weed species of corn. Due to the damage caused to this crop, control measures need to be taken, being the chemical method the most used, due to its ease, effectiveness and low cost when compared to other control methods (Timossi and Freitas, 2011).

Factors such as spacing and plant density may alter weed emergence and, consequently, maize yield. For example, changing row spacing will change the spatial arrangement of plants in the area, increasing or decreasing weed competitiveness (Balbinot and Fleck, 2004). Maize yield increases with reduced row spacing, and increased density also increases plant height and ear insertion height (Demétrio et al., 2008), also reducing weed potential. These factors may be justified by the better use of environmental resources by the crop of economic interest, due to the lower initial competition with weeds.

A tool that supports decision making about when to control weeds, is the economic damage level (NDE). This concept advocates that the application of herbicides or other control methods is only justified if the damage caused by weeds exceeds the cost of the control measure (Kalsin and Vidal, 2013). When there are high weed populations competing with crops, decision making by growers is made easier. However, when weeds appear at low population densities, the adoption of measures to control weeds becomes difficult because of the economic advantages associated with the cost of control (Galon and Agostinetto, 2009).

For crops, plant population is generally constant, while weed population varies according to the soil seed bank and environmental conditions (Galon and Agostinetto, 2009). Knowing the ability of weeds to interfere with the crop is extremely important in deciding which control method to adopt. By knowing the price of the harvested product, the cost of control and the estimated crop yield, it will be possible to determine the level of economic damage by weeds, that is, their density whose interference on the crop will exceed the control cost (Radosevich et al., 2007).

Considering the above, the objective of this study was to evaluate the competitiveness and determine the level of economic damage of weeds in maize.

MATERIAL AND METHODS

The experiment was conducted in field conditions, at the experimental area of the Federal University of Southern Border (UFFS), Campus at Erechim-RS, from November 2016 to April 2017. The maize hybrid used was Syngenta Status, with Viptera 3 biotechnology. Maize was sown under no-tillage system; thirty days before planting, the vegetation was burndown with glyphosate (3.0 L ha^{-1}), followed by paraquat + diuron (2.0 L ha^{-1}) ten days after the first application.

Soil fertility was corrected according to the chemical analysis and following the recommendations of fertilization to maize (ROLAS, 2004). Chemical fertilization in the sowing furrow was 327 kg ha^{-1} of N P K 05 30 15, and nitrogen topdressing was performed V5 and V8, at a dose of 90 kg ha^{-1} of N at each stage.

The experimental design adopted was completely randomized, without replication. In this research, the different Alexandergrass densities provided the necessary variance for the statistical analyzes by the nonlinear model proposed by Cousens (1985). Each experimental unit (plot) comprised an area of 15.0 m^2 (5.0 x 3.0 m), sown with six crop lines spaced in 0.45 m. Treatments included five maize densities: 57,777, 68,888, 81,110, 88,888 and 106,665 plants per hectare (2.60, 3.10, 3.65, 4.00 and 4.80 plants per meter of row, respectively) and Alexandergrass populations: 0, 18, 20, 34, 50, 52, 56, 64, 170 and 228; 0, 38, 46, 54, 72, 88, 108, 152, 236 and 272; 0, 14, 26, 30, 34, 36, 40, 150, 202 and 220; 0, 8, 14, 32, 34, 34, 56, 124, 160 and 220; and 0, 16, 22, 56, 60, 78, 88, 94, 188 and 240 plants m^{-2}, for the densities of 2.60, 3.10, 3.65, 4.00 and 4.80 plants per meter of maize row, respectively, totaling 50 experimental units.

The density of the competing species was established from the soil seed bank by applying ammonium glufosinate (Finale® - 2.0 L ha^{-1}) + adjuvant (Aureo® - 0.5 L ha^{-1}) when the crop was in the phenological stages V3 V4 (20 days after emergence - DAE) and the weed at the stage of two to three leaves. Application at this phenological stage was chosen because it is the most suitable for herbicide application in post-emergence of maize. Alexandergrass plants supposed to be present were protected with plastic cups and buckets, so as not to suffer injuries from the herbicide. The application was carried out by using a CO_2 pressurized precision backpack sprayer equipped with four DG 110.02 fan type nozzles, at constant pressure of 210 kPa and speed of 3.6 km h^{-1}, which provided flow equivalent to 150 L ha^{1}.

Plant density (PP), leaf area (AF), soil cover (CS) and shoot dry mass (MS) of Alexandergrass were assessed 50 days after crop emergence. For PP determination, plants present in two areas of 0.25 m^2 (0.5 x 0.5 m) per plot were counted. CS by Alexandergrass plants was individually evaluated by two researchers, by using a visual percentage scale, where the zero score corresponded to absence of cover and 100 represented total soil cover. AF determination was performed by using a CI 203 BioScience portable leaf area meter, collecting plants in the center of each experimental unit, in an area of 0.5 x 0.5 m (0.25 m^2). After assessing AF, Alexandergrass leaves were placed into kraft paper bags and submitted to drying in a forced air oven at 72 °C until uniformity was obtained for the determination of MS.

Maize grain yield was obtained by harvesting the ears in 3.0 m^2 of each experimental unit, when grain moisture content reached approximately 20%. After grain weighting, moisture was determined and standardized to 13%, extrapolating the results to kg ha^{-1}.

Grain yield losses (%) compared to plots without infestation (control), were estimated according to equation 1:

$$Pp(\%) = \left(\frac{Ra - Rb}{Ra}\right) x100 \quad \text{(eq. 1)}$$

where *Ra* and *Rb*: crop productivity without or with the presence of Alexandergrass, respectively.

Prior to data analysis, MS (g m^{-2}), CS (%) or AF (cm^2) were multiplied by 100, thus eliminating the use of the correction factor in the model (Galon and Agostinetto, 2009).

The relationship between percentage yield losses of maize as a function of the explanatory variables, was calculated separately for each sowing density, by using the non linear regression model derived from the rectangular hyperbole, proposed by Cousens in 1985, according to equation 2:

$$\mathrm{Pp} = \frac{(\mathrm{i} * \mathrm{X})}{(1 + (\frac{\mathrm{i}}{\mathrm{a}}) * \mathrm{X})} \quad \text{(eq. 2)}$$

where: Pp = grain yield loss (%); X = plant density (PP), shoot dry mass (MS), ground cover (CS) or leaf area (AF) of Alexandergrass; and *i* and *a* = yield losses (%) per unit of Alexandergrass plants when the value of the variable approaches zero or tends to infinite, respectively.

Data were adjusted to the model by the *Proc Nlin* procedure of the SAS computer software. For the calculation procedure, the Gauss-Newton method was used, which, by successive interactions, estimates the values of the parameters in which the sum of the squared deviations from the observations in relation to the adjusted ones is minimal.

The value of the F statistic (p£0.05) was used as a criterion for adjusting the model to the data. The acceptance criterion of model fit to the data was based on the highest value of the coefficient of determination (R^2) and the smallest value of the mean square of the residue (QMR).

In calculating the economic damage level (NDE), we used the estimates of parameter *i* obtained from Equation 2 (Cousens, 1985) and the adapted equation of Lindquist and Kropff (1996) – Equation 3:

$$NDE = \frac{(Cc)}{\left(R * P * \left(\frac{i}{100}\right) * \left(\frac{H}{100}\right)\right)} \quad \text{(eq. 3)}$$

where: NDE = economic damage level (plants m^{-2}); *Cc* = cost of control (herbicide and tractor-towed application in dollars ha^{-1}); *R* = maize grain yield (kg ha^{-1}); *P* = maize price (dollars kg^{-1} of grains); *I* = maize yield loss (%) per unit of competing plant when density level approaches zero; and *H* = herbicide efficiency level (%).

For Cc, R, P and H (Equation 3), three values were estimated. 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. Maize grain yield (R) was based on the lowest (3,786 kg ha^{-1}), average (4,426 kg ha^{-1}) and highest (5,291 kg ha^{-1}) yields obtained in Brazil in the last 10 years. Product price (P) was estimated considering the lowest (\$ 6.00), medium (\$ 9.00) and highest (\$ 14.00) maize prices paid per 60 kg sack in the last 10 years (CONAB, 2018). The values for herbicide efficiency (H) were established in the order of 80%, 90% and 100% control efficiency.

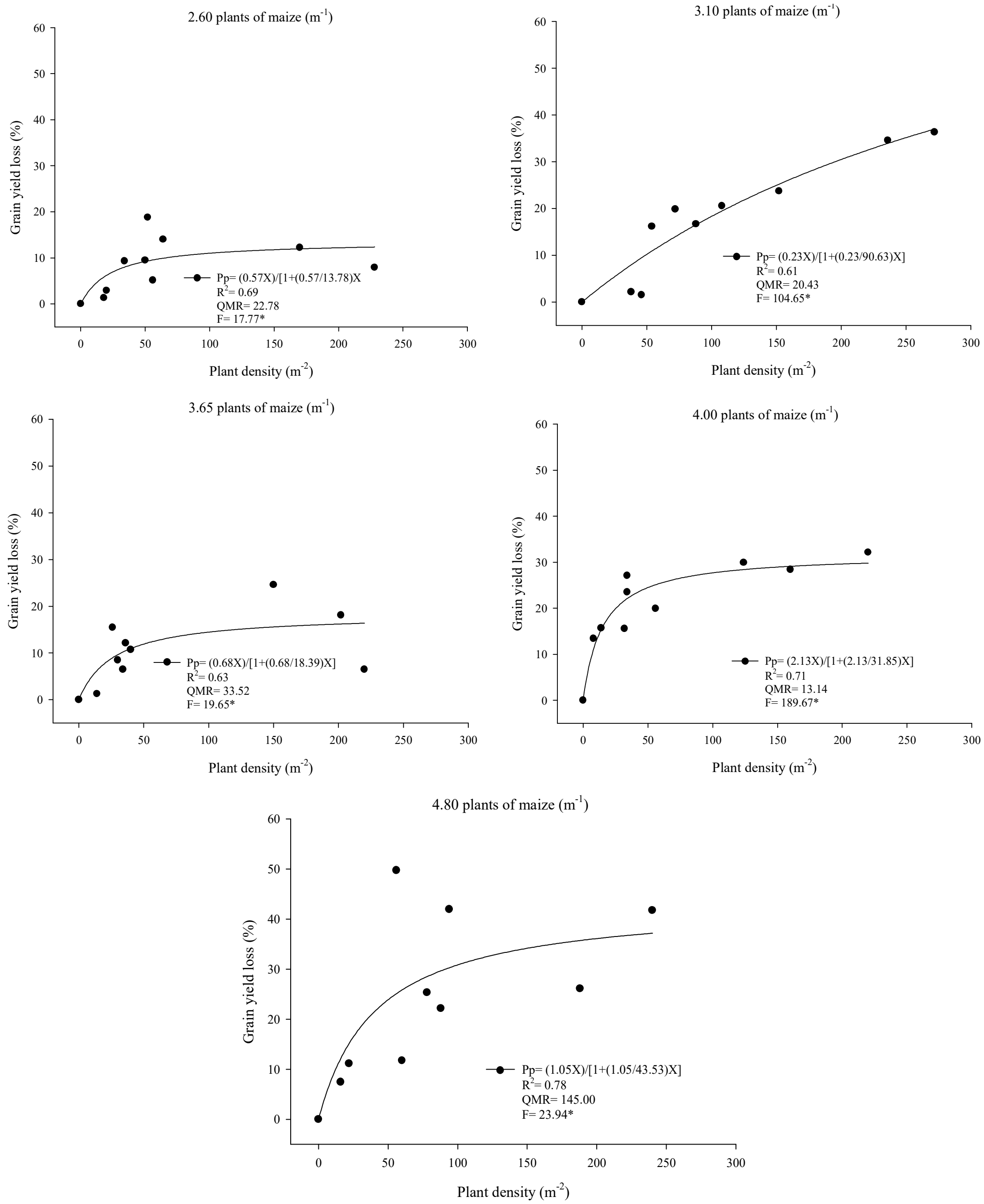
RESULTS AND DISCUSSION

For PP, AF, CS and MS of Alexandergrass, there was significance for all maize densities (Figures 1, 2, 3 and 4). At all densities (2.60, 3.10, 3.65, 4.00 and 4.80 plants m^{-1}) the rectangular hyperbole model fit the data appropriately, with R^2 values greater than 0.58 and low QMR, which characterizes good fit of model to the data. These results corroborate those obtained by Cargnelutti Filho and Storck (2007), who, observing the effect of cultivars and the heritability of maize hybrids, considered as moderate to good values of R^2 between 0.57 and 0.66.

The estimated values for parameter *i* tended to be lower for maize densities of 2.60, 3.10 and 3.65 plants m^{-1}, for all evaluated characteristics - PP, AF, CS and MS (Figures 1, 2, 3 and 4). In the same comparison, it was observed that the lowest competitiveness was obtained for the densities of 4.00 and 4.80 plants m^{-1} of the Syngenta Status Viptera 3 maize hybrid, which suffered the largest losses in grain yield compared to other densities (Figures 1, 2, 3 and 4). Some studies have reported differences between maize densities in terms of the crop's competitive ability in the presence of weeds, a fact attributed to both intra-and inter-specific competition between species involved in the community (Balbinot and Fleck, 2004).

Flesch and Vieira (2004), by decreasing the spacing and increasing density of different maize hybrids, found that this practice was effective in weed control. Thus, in some situations, even if reduced spacing does not result in increased grain yield, its adoption may be justified by the gain in competitiveness of the crop over weeds due to the higher amount of radiation intercepted by maize (Teasdale, 1995).

The lower competitiveness in sowing densities of 4.00 and 4.80 plants m^{-1}, when compared to 2.60, 3.10 and 3.65 plants m^{-1} (Figures 1, 2, 3 and 4), may be due to the fact that increasing the density of maize plants leads to competition for nutrients, water and light available in the environment among plants of the crop itself. The more individuals present in an area above the recommended amount for that cultivar, the more detrimental the growth and development of the species. Positive responses to increased maize grain yields have been observed by population growth, with yields peaking between 70,000 and 80,000 plants ha^{-1}, declining in higher populations (Kappes et al., 2011), which corroborates the results of the present work.

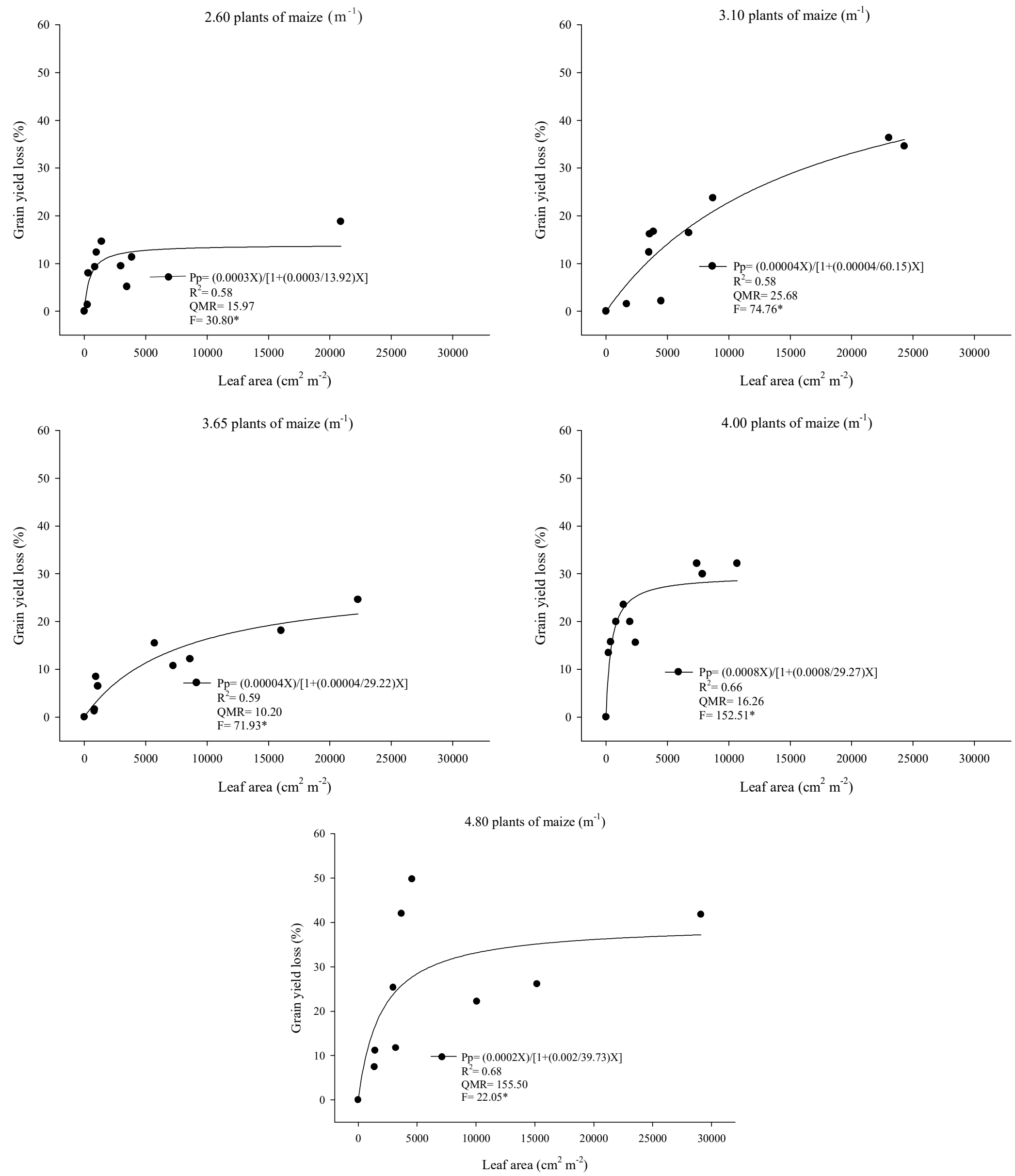


R^2: determination coefficient; QMR: residual mean square; * Significant at p≤0.05.

Figure 1 - Grain yield loss (Pp) of the maize hybrid Syngenta Status Vip3, at the density of 2.60, 3.10, 3.65, 4.00 and 4.80 maize plants m^{-1}, as a function of Alexandergrass plant density, 50 days after emergence.

Comparing maize sowing densities for PP, based on unit loss (*i*), yield losses of 0.54, 0.22, 0.65, 1.99 and 1.02% were observed for the densities of 2.60, 3.10, 3.65, 4.00 and 4.80 plants m^{-1}, respectively (Figure 1). According to Kappes et al. (2011), changes in spacing between maize lines mainly alter intraspecific competition. Regardless of the spacing used, there is intraspecific competition in roots for nutrients and water; when row spacing is reduced, competition between maize plants in the seeding row is also reduced (Nummer Filho and Hentschke, 2006), as plants are better distributed.

There was 1.25% grain yield loss in maize densities for AF (5000 cm^2 m^{-2}), and in the densities of 2.60, 4.00 and 4.80 plants m^{-1} the highest losses occurred (1.35, 3.52 and 1.00%). When analyzing maize in relation to the highest PA of Alexandergrass (30,000 cm^2 m^{-2}), the same aspect was observed when comparing the lowest PA (5,000 cm^2 m^{-2}), where at densities of 2.60,



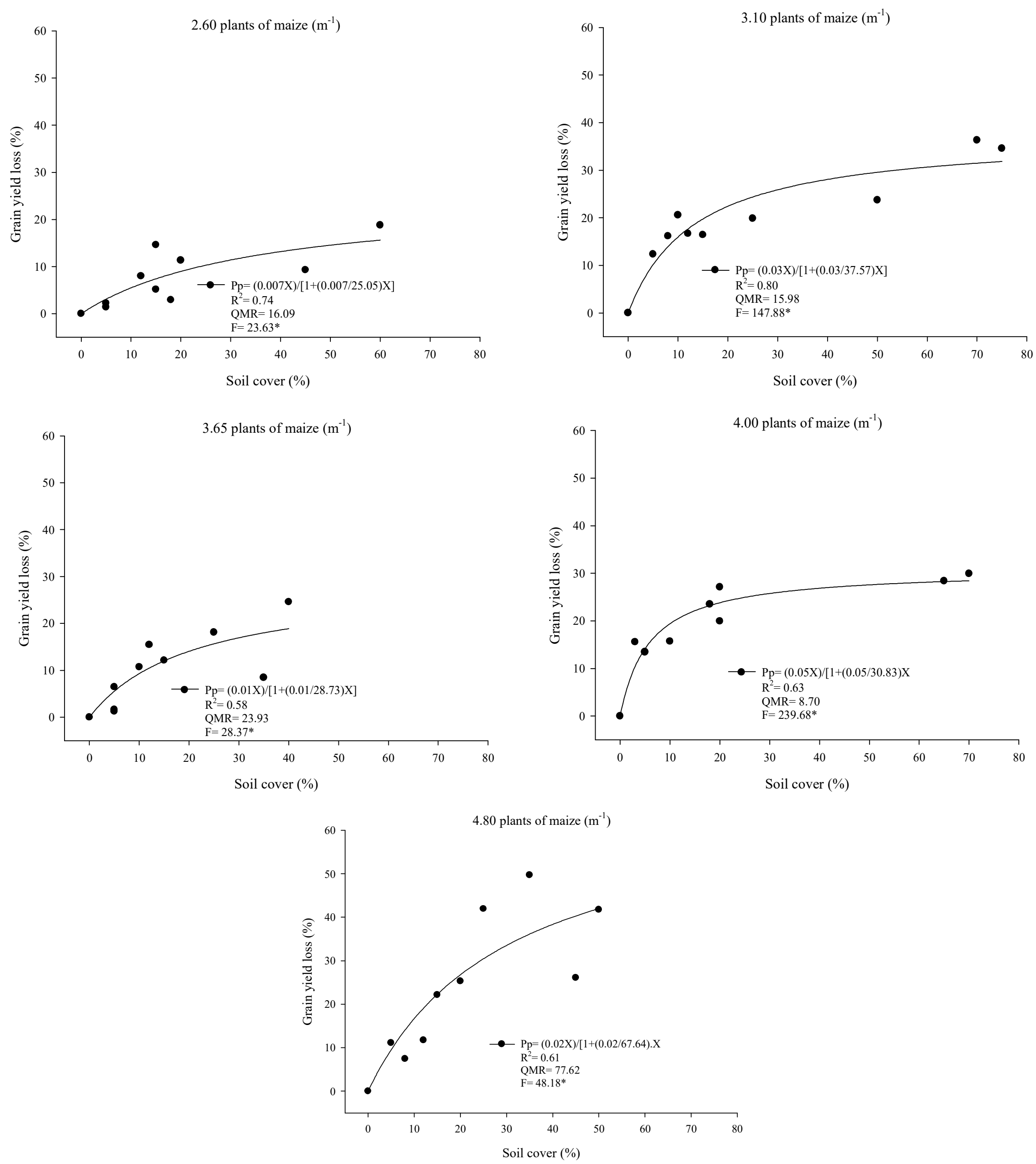
R^2: determination coefficient; QMR: residual mean square; * Significant at $p \leq 0.05$.

Figure 2 **-** Grain yield loss (Pp) of the maize hybrid Syngenta Status Vip3, at the densities of 2.60, 3.10, 3.65, 4.00 and 4.80 maize plants m^{-1}, as a function of Alexandergrass leaf area, 50 days after emergence.

4.00 and 4.80 plants m^{-1} the highest losses were reported: 5.47, 13.19 and 5.21%, respectively (Figure 2A, 2D and 2E). It can be inferred that the degree of weed competition against maize is influenced by leaf area, that is, the more leaf area attriuted to the weed, the most competitive it will be with the crop, as also found by Galon et al. (2018). These authors observed that, as Alexandergrass appeared in a larger proportion of plants than saccharin sorghum, the weed obtained larger leaf area compared to the crop and, consequently, presented greater competitive ability.

The results for maize yield losses, in relation to the percentage of soil cover (Figure 3), demonstrate the same tendency of those observed for plant density (Figure 1). It can be stated that in maize sown at the highest densities (4.00 and 4.80 plants m^{-1}) the largest grain yield reductions occurred when the soil was about 10% covered by Alexandergrass.

By accumulating 80 g m^{-2} of dry mass, Alexandergrass caused the largest reductions in maize grain yield, which were 7.80 and 2.96% for sowing densities of 4.00 and 4.80 plants m^{-1},



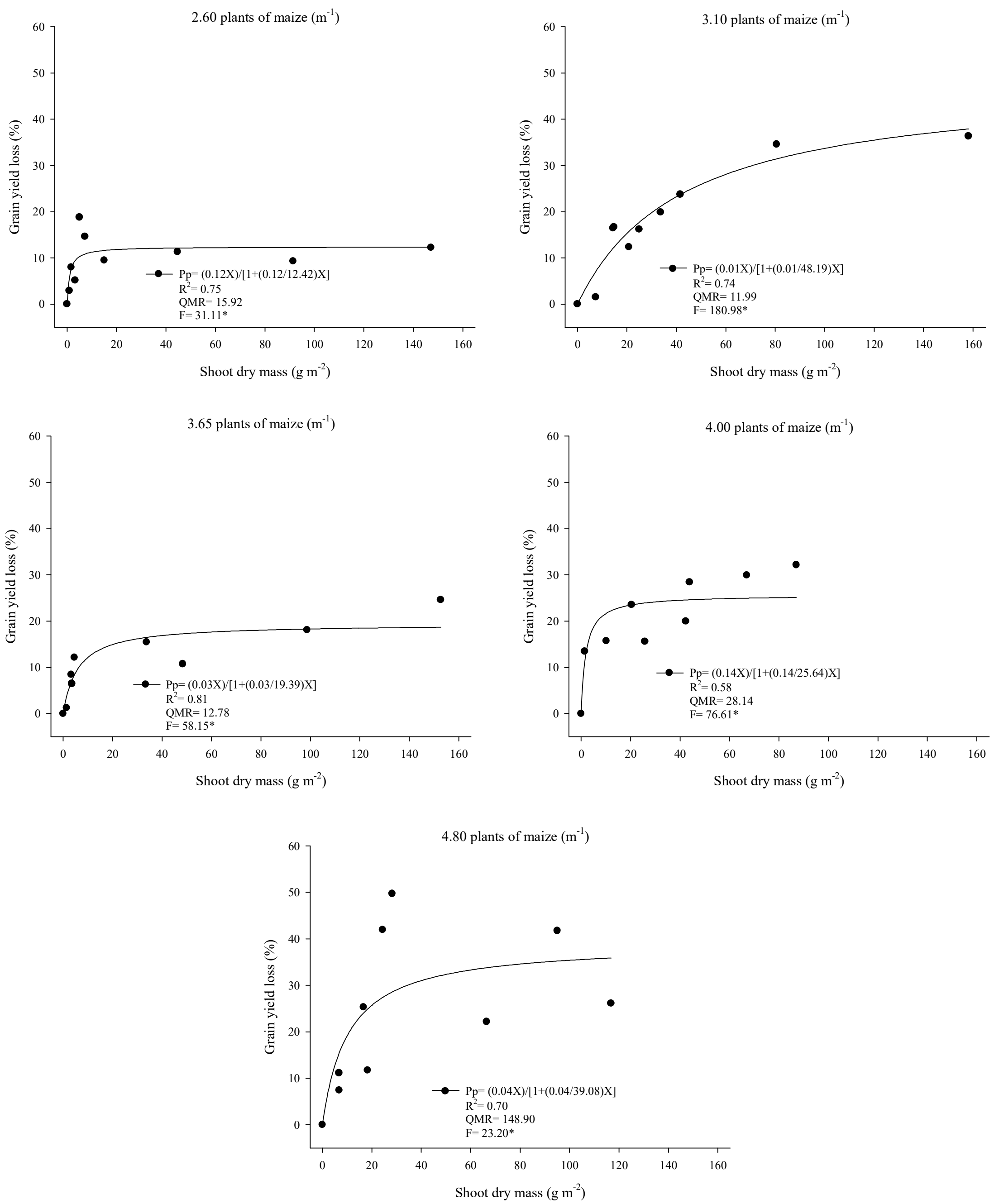
R^2: determination coefficient; QMR: residual mean square; * Significant at $p \leq 0.05$.

Figure 3 **-** Grain yield loss (Pp) of the maize hybrid Syngenta Status Vip3, at the densities of 2.60, 3.10, 3.65, 4.00 and 4.80 maize plants m^{-1}, as a function of soil cover (%) by Alexandergrass plants, 50 days after emergence.

respectively (Figure 4D and 4E). This corroborates results reported for PP (Figure 1), AF (Figure 2) and CS (Figure 3), where in these two densities the highest losses of maize grain yield were observed. Carvalho et al. (2014), when evaluating the competition of corn with *Ipomoea hederifolia*, also found reductions in growth and accumulation of crop macronutrients when these species were kept together, which is consistent with the results of the present study.

Because parameter *i* is an index used to compare relative competitiveness among species (Swinton et al., 1994), different values for maize densities were observed in the explanatory variables tested (Figures 1, 2, 3 and 4).

The comparison between maize densities considering the parameter *i*, in the average of the four explanatory variables (PP, CS, AF or MS), showed that the competitiveness ranking was: 3.10 > 2.60 > 3.65 > 4.80 > 4.00 (Figures 1, 2, 3 and 4). Differences observed between densities are largely due to the better use of space or resource availability, or the occurrence of a high



R^2: determination coefficient; QMR: residual mean square; * Significant at $p \leq 0.05$.

Figure 4 - Grain yield loss (Pp) of the maize hybrid Syngenta Status Vip3, at the densities of 2.60, 3.10, 3.65, 4.00 and 4.80 maize plants m^{-1}, as a function of Alexandergrass shoot dry mass, 50 days after emergence.

standard error in the estimation of parameter *i*, which can be attributed to the natural variability associated to field experiments and/or crop phenotypic plasticity (Dieleman et al., 1995). Studies by Sangoi (2000) suggests that there is less competition between plants within the same planting row for light, water and nutrients, due to their more equidistant distribution in the area, thus increasing the availability of carbohydrates, which will allow the plant to form larger numbers and heavier grains.

It was observed that the explanatory characteristics presented distinct parameters *i* for the maize densities (Figures 1, 2, 3 and 4), that is, there is differentiation in the degree of competition between the crop and the weed according to the sowing densities. Similarly, Nummer Filho and Hentschke (2006) state that the use of reduced spacing is a weed management practice in maize crop and that, under low light conditions, low rainfall and nutrient deficiency, plants grown in reduced spacing may show greater use of limited resources. The authors report that this occurs, among other factors, due to differences in competitive capacity that densities present, which causes lower loss of grain yield per weed individual. This corroborates the result found in the present study, where the density of 3.10 plants m^{-1} presented the lowest grain yield loss, although it was one of those that showed lower grain yields (7.5 t ha^{-1}) compared to 2.60, 3.65, 4.00 and 4.80 plants m^{-1}, with yields of 7.8, 8.5, 7.8 and 6.9 t ha^{-1}, respectively.

The estimates of the parameter *a*, regardless of the explanatory variable, were all below 100% (Figures 1, 2, 3 and 4), demonstrating that it was possible to adequately simulate the maximum yield losses of maize with the used populations of Alexandergrass. It also emphasized that the higher the crop productive potential, if the soil fertility, water availability and light conditions are adequate, the lower the daily percentage loss caused by a given weed species (Kalsing and Vidal, 2013).

The comparison between the explanatory characteristics for all evaluated maize densities, in general, showed a better model fit for the variables MS > CS > AF > PP, considering the highest average R^2 and the lowest average QMR values (Figures 1, 2, 3 and 4). This aspect shows that MS can be used as a substitute for other variables to estimate maize grain yield losses.

Successful implementation of Alexandergrass management in maize planting systems may stem from the determination in the population that exceeds the NDE. Thus, it was observed that the densities of 2.60 and 3.10 plants m^{-1} of maize presented the highest NDE values in all simulations, ranging from 5.91 to 42.78 plants m^{-2} (Figures 5, 6, 7 and 8). The lowest NDE values were obtained with the densities of 4.00 and 4.80 plants m^{-1} of maize, ranging from 1.58 to 9.37 plants m^{-2} (Figures 5, 6, 7 and 8). The density of 3.65 plants m^{-1} of maize was at an intermediate level of NDE compared to the other densities.

In the average of all maize densities, and comparing the lowest with the highest grain yield, there was a difference in NDE of 72% (Figure 5). Thus, the higher the yield potential of maize densities, the smaller the maize plant population needed to reach the NDE, making the adoption of Alexandergrass control measures compensatory. Vidal et al. (2004) state that Alexandergrass NDE on irrigated maize rises as crop price decreases, increasing control cost; rising maize price reduces impact of weed control cost on economic return.

The average result when considering all evaluated densities, the highest versus the lowest price paid per bag of corn, showed a 2.9 fold variation in the NDE value (Figure 6). Therefore, the

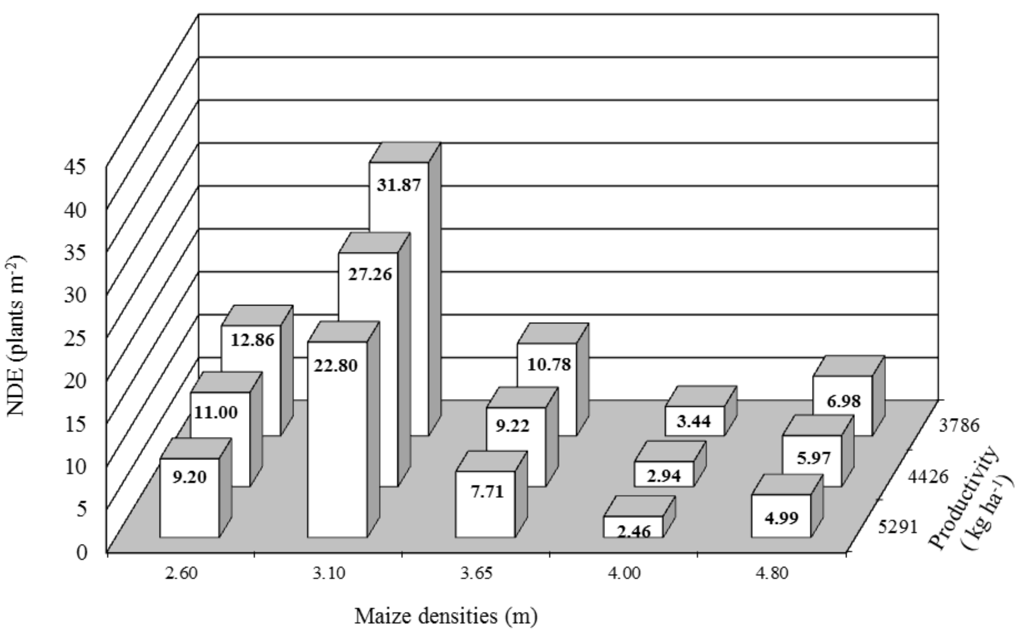


Figure 5 - Economic damage level (NDE) for the maize hybrid Syngenta Status Vip3, as a function of crop grain yield (kg ha^{-1}), Alexandergrass density (plants m^{-2}) and maize density (plants m^{-1}).

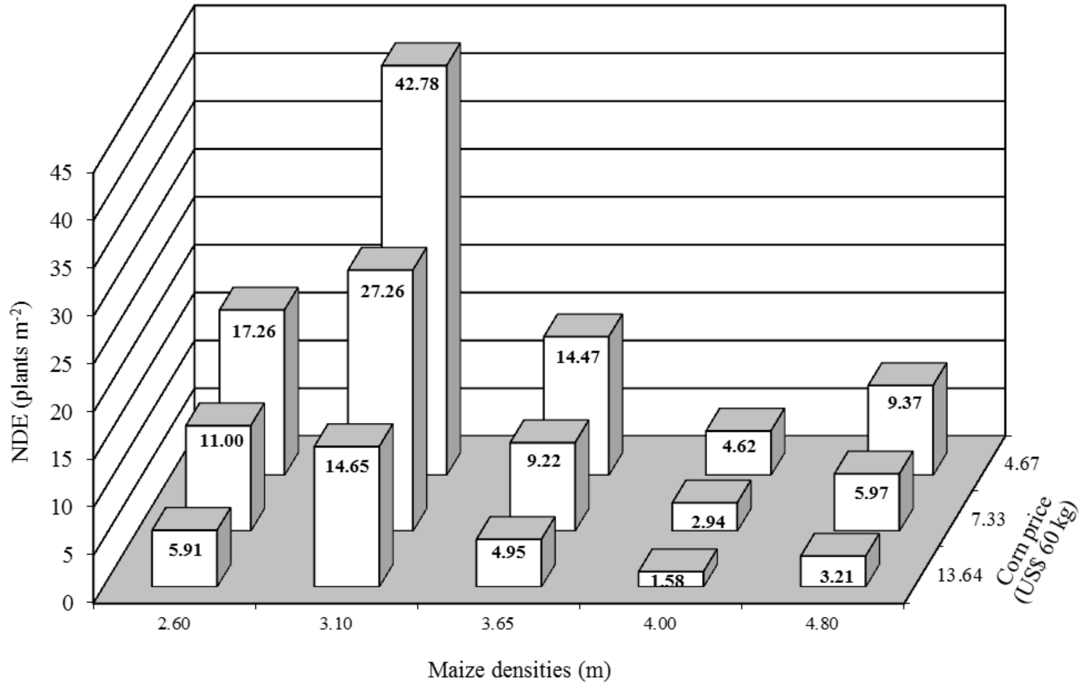


Figure 6 - Economic damage level (NDE) for the maize hybrid Syngenta Status Vip3, as a function of corn bag price (U$), Alexandergrass density (plants m^{-2}) and maize density (plants m^{-1}).

lower the price paid per grain bag, the larger will be the required population of Alexandergrass to surpass the NDE, aiming to make the control method economically interesting.

Regarding the efficiency of the chemical control method with herbicides, it was observed that the average efficiency (90%), when compared to the lowest (80%) or the highest (100%), showed alterations in NDE of 11% and 12%, respectively (Figure 7). Thus, the control level influences the NDE, and the higher the herbicide efficiency, the lower the NDE (lower number of plants m^{-2} needed to adopt control measures). These results corroborate those observed for the competition between rice and barnyardgrass (Galon and Agostinetto, 2009), between beans and Alexandergrass (Kalsing and Vidal, 2013) and between maize and Alexandergrass (Vidal et al., 2004).

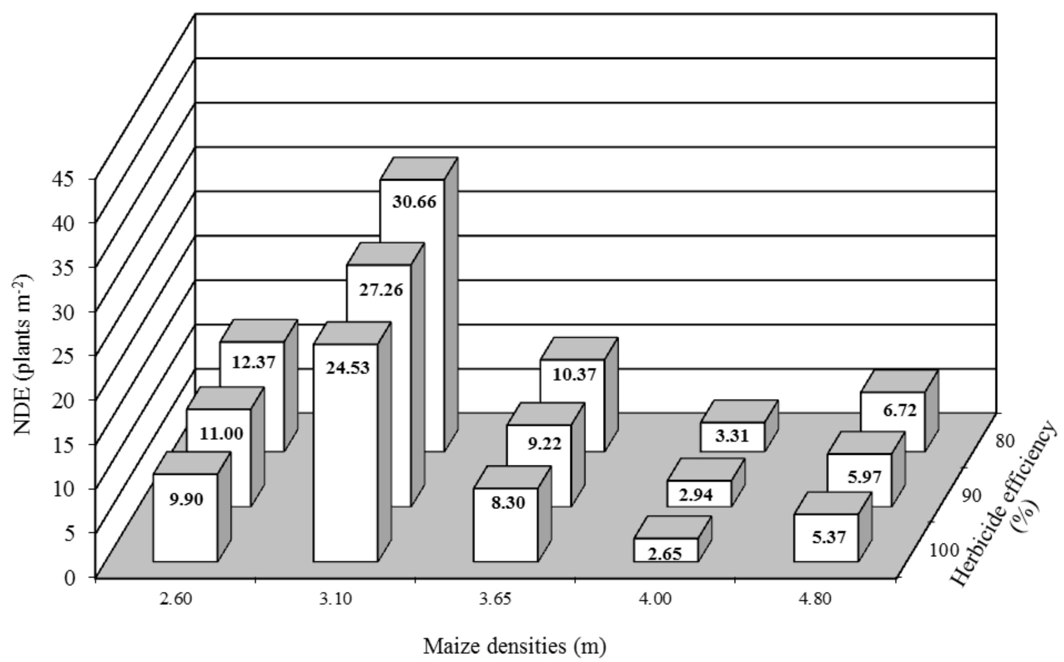


Figure 7 - Economic damage level (NDE) for the maize hybrid Syngenta Status Vip3, as a function of herbicide efficiency (%), Alexandergrass density (plants m^{-2}) and maize density (plants m^{-1}).

Regarding the control cost of Alexandergrass at all densities, it was observed that the minimum cost was 60% lower when compared to the maximum cost. Thus, the higher the cost of the control method, the higher the NDEs and the more Alexandergrass plants m^{-2} are needed to justify control measures (Figure 8). The use of NDE as a tool for weed management should be associated with good maize management agricultural practices, as its implementation is only justified in crops that use crop rotation, appropriate plant arrangement, hybrids with higher competitive ability, appropriate sowing timings and soil fertility correction, among others.

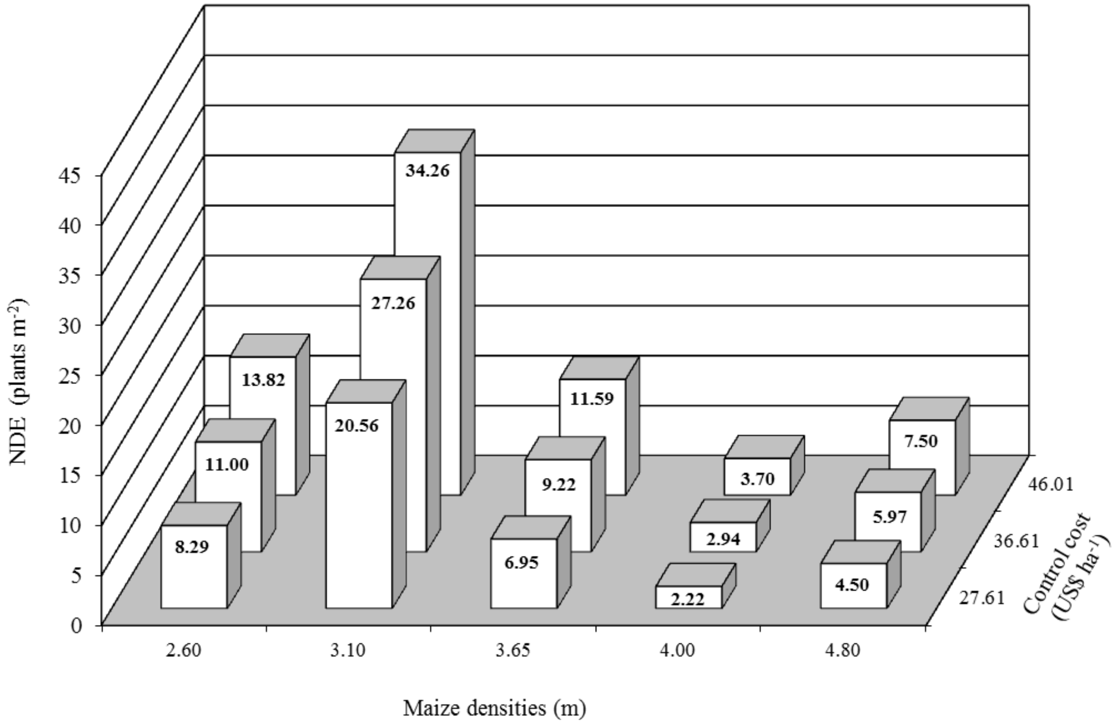


Figure 8 - Economic damage level (NDE) for the maize hybrid Syngenta Status Vip3, as a function of control cost (U\$ ha^{-1}), Alexandergrass density (plants m^{-2}) and maize density (plants m^{-1}).

The results support the conclusion that the nonlinear regression model of rectangular hyperbole adequately estimates losses in maize grain yield in the presence of Alexandergrass population. Sowing of maize at densities of 2.60, 3.10 and 3.65 plants m^{-1} has greater competitive ability against Alexandergrass than the densities of 4.00 and 4.80 plants m^{-1}. NDE values ranged from 1.58 to 9.37 plants m^{-2} for densities of 4.00 and 4.80 plants m^{-1} of maize, which showed less competitiveness with Alexandergrass. The highest NDE values ranged from 5.91 to 42.78 plants m^{-2} for the densities of 2.60, 3.10 and 3.65 plants m^{-1}, which showed the highest competitiveness against Alexandergrass. NDEs decrease with increasing grain yield, corn bag price, herbicide efficiency and with the reduction in the control cost, justifying the adoption of control measures in smaller weed populations.

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