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INTERFERENCE AND ECONOMIC THRESHOLD LEVEL OF TRANSGENIC VOLUNTEER SOYBEAN PLANTS IN MAIZE CROP

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Abstract – The interference caused by volunteer plants dispersed after harvest can cause economic losses to growers. This work aims to identify the competitive ability and the economic threshold level of maize hybrids in different densities of volunteer soybean. The experiment was carried out in the field, in a randomized blocks design, with one replication. The treatments were maize hybrids (NK 422 Vip3; NK 488 Vip3; Syn Supremo Vip3; Brevant 2A401 PWU; FS 481 PW; e FS 620 PWU) and 12 densities of volunteer soybean established for each hybrid, going from 0 to maximum of 130 plants m^{-2}. At 30 days after emergence, were assessed the plant density (PD), soil cover (SC), leaf area (LA), and shot dry mass (SDM) of volunteer soybean plants. The maize hybrids NK 488 Vip3, Syn Supremo Vip3, and Brevant 2A401 PWU showed the highest competitive abilities that influenced economic threshold levels that ranged from 1,01 to 3,82 plants m^{-2}. Thus, it concluded that volunteer soybean causes yield losses when infesting maize, and hybrids show different competitive abilities, being the economic threshold level directly influenced by these characteristics.

Keywords: *Zea mays*, *Glycine max*, Genetically modified crops.

INTERFERÊNCIA E NÍVEL DE DANO ECONÔMICO DE PLANTAS VOLUNTÁRIAS DE SOJA TRANSGÊNICA EM MILHO

Resumo - A interferência ocasionada por plantas voluntárias, provenientes de sementes perdidas após à colheita, podem ocasionar prejuízos econômicos aos agricultores. O objetivo deste trabalho foi identificar a habilidade competitiva e o nível de dano econômico de híbridos de milho na presença de diferentes densidades de soja voluntária. O experimento foi conduzido a campo, em delineamento de blocos casualizados, com uma repetição. Os tratamentos foram constituídos pelos híbridos de milho (NK 422 Vip3; NK 488 Vip3; Syn Supremo Vip3; Brevant 2A401 PWU; FS 481 PW; e FS 620 PWU) e 12 densidades de soja voluntária estabelecidas para cada híbrido, saindo de 0 ao máximo de 130 plantas m^{-2}. Aos 30 dias após a emergência, efetuou-se a quantificação da densidade de plantas (DP), cobertura de solo (CS), área foliar (AF) e massa seca da parte aérea (MS) das plantas voluntárias de soja. Os híbridos de milho NK 488 Vip3, Syn Supremo Vip3 e Brevant 2A401 PWU apresentam as maiores habilidades competitivas o que refletiu em NDE que variou de 1,01 a 3,82 plantas m^{-2}. Desta forma, pode-se concluir que a soja voluntária ocasiona perdas de produtividade ao infestar o milho, sendo que os híbridos apresentam habilidades competitivas diferenciadas e o NDE é influenciado diretamente por estas características.

Palavras-chave: *Zea mays*, *Glycine max*, Culturas geneticamente modificadas.

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Brazil is characterized as the second-largest maize producer in the world, producing in 2020/21 crop, approximately 87 million tons in an area of 20 million hectares (Acompanhamento da Safra Brasileira de Grãos, 2021). Second-crop maize was responsible for around 75% of this grain volume, occupying an area of 14.99 million hectares, with average productivity of 5.5 t ha^{-1} (Acompanhamento da Safra Brasileira de Grãos, 2021). Second-crop maize is known for being sown mainly after the early soybeans. In this way, the management of these two cultures is directly related. Cultural practices performed in one reflect immediately in the other culture. The grain losses at harvest of these crops have caused an expansion in the incidence of volunteer plants in the succession crop. They can compete for space, water, nutrients, light, and host pests and diseases (Alms et al., 2016; Petter et al., 2016; Piasecki & Rizzardi, 2018; Rizzardi et al., 2019).

With the introduction of glyphosate-resistant soybean and maize (GR) crops, volunteer plants have become commonplace in this succession of crops. However, the control of volunteer soybeans, even though it is a legislative and mandatory measure in several states of the federation, is often neglected. High densities of plants competing with crops simplify the decision of producers to adopt some control measure (Agostinetto et al., 2010). However, when volunteer plants occur at lower densities, adopting measures to control them becomes difficult, as farmers need to quantify the economic benefits associated with the control cost (Galon et al., 2019). Thus, it is necessary to implement management strategies that integrate technical knowledge and economic analysis with the competitive relationship between crops and weeds (Westwood et al., 2018). Within this context, it is essential to characterize the level of economic damage (NDE) to assist the producer in decision making.

The NDE states application of herbicides or other control methods is only justified if the damage caused by the weeds is greater than the cost of the measure used (Tavares et al., 2019; Frandoloso et al., 2020). To perform NDE calculations involves many variables. The variables are under the influence of several factors such as weed species present in the field, weed density and emergence time with the crop, percent loss and yield potential of the crop in the presence and free of weeds, the value of the harvested product, costs, and efficiency of control, and influence of the remaining weeds on the product (Brandler et al., 2021). In addition, management practices, including cultivars with greater competitiveness and sowing densities, can directly influence the level of losses caused by weeds. This information can help growers in their decision-making.

There are variations in the competitive ability and the economic damage levels caused by the competition exerted by volunteer soybean to maize hybrids, NK 422 Vip3, NK 488 Vip3, Syn Supremo Vip3, Brevant 2A401 PWU, FS 481 PW e FS620 PWU, depending on the density of competitor plants and hybrid evaluated.

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Therefore, this study aimed to identify the competitive ability of six maize hybrids in the presence of different volunteer soybean densities and determine the economic damage of these materials.

Material and Methods

The experiment was field conducted in the experimental area of the Universidade Federal da Fronteira Sul (UFFS), Campus Erechim/RS, latitude 27.725269º S, longitude 52.294485º W, and altitude 650 m, in the 2017/18 crop year. The soil of the experimental area is a Red Latosol Alumino Ferric Humic (Santos et al., 2018). Soil samples were taken in the 0 to 10 cm layer to perform the chemical analysis, having the following characteristics: pH (water) = 5.1; organic material = 3.0%; clay = >60%; P = 5.2 mg dm^{-3}, K = 118.0 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}; CTC effective = 16,6 cmolc dm^{-3}. Fertility corrections followed the technical recommendations for grain maize culture (Manual…, 2016). The base chemical fertilization was 430 kg ha^{-1} of the formula 05-30-15 of N-P-K, and the application of N in coverage occurred in two moments, at the V4 and V6 stages of the crop, at a dose of 60 kg ha^{-1} of N or 134 kg ha^{-1} of urea (45% N) at each stage of maize. The other managements adopted the technical recommendations for the maize crop.

The experiment consisted of a randomized block design, with one repetition of six maize hybrids and 12 volunteer soybean densities. In this research, the different densities of volunteer soybeans worked as repetitions, providing the necessary variance to perform the statistical analysis by the nonlinear rectangular hyperbola model proposed by Cousens (1985).

The maize hybrids used were: NK 422 Vip3 (H1), NK 488 Vip3 (H2), Syn Supremo Vip3 (H3), Brevant 2A401 PWU (H4), FS 481 PW (H5) e FS620 PWU (H6). These hybrids underwent coexistence with different densities of volunteer soybean: : H1 *versus* 0, 4, 14, 14, 18, 20, 28, 30, 42, 50, 66 e 66 plants m^{-2}; H2 *versus* 0, 14, 22, 22, 28, 34, 42, 34, 38, 44, 54 e 130 plants m^{-2}; H3 *versus* 0, 12, 14, 18, 28, 32, 32, 36, 36, 48, 54, e 82 plants m^{-2}; H4 *versus* 0, 6, 10, 18, 24, 34, 40, 42, 44, 54, 54 e 56 plants m^{-2}; H5 *versus* 0, 4, 4, 10, 10, 28, 30, 34, 42, 46, 50 e 94 plants m^{-2}; e H6 *versus* 0, 4, 8, 10, 20, 22, 28, 32, 40, 48, 50 e 58 plants m^{-2}.

The maize hybrids selected for the present study were those most widely grown in the region for grain production, with the characteristics: a) NK 422 Vip3: super-early cycle, insect-resistant, and herbicide-tolerant. b) NK 488 Vip3: super-early cycle, insect-resistant, and herbicide-tolerant. c) Syn Supremo Vip3: early cycle, insect-resistant, and herbicide-tolerant. d) Brevant 2A401 PWU: super-early cycle, insect-resistant, and herbicide-tolerant. e) FS 481 PW: super-early cycle, insect-resistant and herbicide-tolerant; and f) FS620 PWU: early cycle, insect-resistant, and herbicide-tolerant.

The experiment started a no-tillage system on November 7, 2017. The soil mulch was

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formed by black oat + vetch, producing 5 t ha-1 of dry mass. Desiccation consisted of glyphosate herbicide (1440 g e.a. ha^{-1}) 15 days before maize sowing. The experimental units presented an area of 15.0 m^2, composed of six maizerows spaced at 0.5 m and 5 m long. The usable area corresponded to the three central rows, discounting one linear meter from each extremity (1.5 m x 3 m). The hybrid sowing density was 3.5 seeds per linear meter or 70,000 seeds ha^{-1}.

The volunteer soybean (Glycine max) densities were established by planting the cultivar NS 5909 using a hand planter machine. The establishment of volunteer soybean densities allowed to simulate different harvest losses, from low to high amounts of grain lost in the field, by calculating the amount of seed needed in each experimental unit according to the proposed treatment, from 0 to 130 plants m^{-2}. The volunteer soybean densities varied because sowing with a manual drill presents unequal depth from one pit to another. This situation occurs because the soil is sometimes more compacted and has more straw. Also, factors such as soil humidity and temperature may have influenced the establishment of an exact number of plants per area (experimental unit). The densities of volunteer soybean were determined by measurements in two 0.5 x 0.5 m areas, with one in the center and another on the side of each experimental unit, when maize was at the V4 stage (four expanded leaves) and the weed, at the V3 stage (third trefoil). The other plants not studied were controlled with glyphosate application (1440 g e.a. ha^{-1}) to eliminate competition.

The measurement of plant density (DP), ground cover (CS), leaf area (AF), and aboveground dry mass (MS) of soybean volunteer plants occurred 30 days after emergence (DAE) or at the V4-V5 phenological stage of maize. The determination of the explanatory variable DP occurred through two random samplings per plot using a 0.5 m square. The SC by volunteer soybean plants was evaluated visually and individually by two evaluators, using a percentage scale with zero corresponding to the absence of coverage and 100 representing total soil coverage. The quantification of competing plant AF consisted of a portable electronic PA integrator, model CI-203, brand CID Bio-Science, measuring all plants in an area of 0.25 m^{-2} per plot. The determination of MS in volunteer soy plants (g m^{-2}) consisted in collecting plants from 0.25 m^2 (0.5 x 0.5 m) per plot and drying them in a forced air oven at a temperature of 60±5ºC until they reached constant mass.

The harvesting plants in a working area of 8 m^2 (2 x 4 m) per plot quantified the grain yield. The harvest occurred when the average moisture content of the grains reached approximately 15%. After weighing, their moisture content was determined, with the masses corrected to 13% moisture content and the values expressed in kg ha^{-1}.

The calculation of the percentage losses of maize grain yield concerning experimental units free of competing plants comes from Equation 1:

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

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

Before data analysis, the values of MS (g m^{-2}), SC (%), or AF (cm^2) were multiplied by 100, dispensing the use of the correction factor in the model (Agostinetto et al., 2010; Tavares et al., 2019; Frandoloso et al., 2020).

The relationships between percent maize yield losses as a function of the explanatory variables were calculated separately for each maize hybrid, using the nonlinear regression model derived from the rectangular hyperbola, proposed by Cousens in 1985, according to Equation 2:

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

Where: Pp = yield loss (%); X = density, aboveground dry mass, leaf area, or ground cover of volunteer soybean; i and a = yield losses (%) per unit of volunteer soybean plants when the value of the variable approaches zero and when it tends to infinity, respectively. For the calculation procedure, the Gauss-Newton method was adopted, 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 (Ratkowsky, 1983). The value of the F statistic ($p \leq 0.05$) provided the criteria for analyzing the data in the model. The criteria for accepting the fit of the data to the model are based on the F significance, the highest value of the coefficient of determination (R^2), and the smallest mean square value of the residual (QMR).

To calculate the level of economic damage (NDE), the parameter i estimates are obtained from Equation 2 (Cousens, 1985) and the Equation adapted from Lindquist and Kropff (1996) - Equation 3:

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

where: NDE = economic damage level (plants m^{-2}); Cc = control cost (commercial herbicide mix, atrazine+simazine - 1500 + 1500 g ha^{-1} and terrestrial tractor application, in dollars ha^{-1}); R = maize grain yield (kg ha^{-1}); P = maize price (dollars kg^{-1} grain); i = loss (%) of maize yield per competing plant unit, when the population level approaches zero and H = herbicide efficiency level (%).

For the variables Cc, R, P, and H (Equation 3), three values occurring in the last 10 (ten) years formed a weight. Thus, for the control cost (Cc), the average price considering the maximum and minimum cost varied by 25% concerning the average cost. The maize grain productivity (R) was based on the lowest average, and highest obtained in the Rio Grande do Sul in the last ten years. The product price (P) has weighted from the lowest, average, and highest price of maize paid at 60 kg over the

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last ten years. The herbicide efficiency (H) values averaged 80, 90, and 100% control, with 80% as the minimum effective weed control (Velini et al., 1995). For the other variables, intermediate values were assumed in the NDE simulation.

Results and Discussion

The explanatory variables of volunteer soybean DP, AF, CS, and MS evaluated for yield loss in hybrids showed significant F-statistic values (Table 1). The rectangular hyperbola model fitted the data adequately, with a mean R^2 value greater than 0.57 and a low QMR. This fact characterizes a good fit of the data to the model in which it was tested. The observed results agree with those Galon et al. (2019) found when evaluating the competition of alexandergrass (*Urochloa planaginea*) with five maize hybrids, which found average R^2 values for the same variables of the present study higher than 0.52. Works related to genetic variation, the effect of cultivars, and the heritability of maize hybrids, consider as moderate to good, with R^2 values between 0.57 to 0.66 (Cargnelutti Filho & Storck, 2007).

The maize hybrids showed different levels of yield losses (Table 1). The materials NK 488 Vip3, Syn Supremo Vip3, and Brevant 2A401 PWU characterized the most competitive genotypes. It is due to the lower yield losses compared to the other hybrids. Research shows the differentiated capacity of maize hybrids regarding their competitive ability in the presence of weeds (Williams et al., 2008; Galon et al., 2019; Frandoloso et al., 2020). The difference in competition among maize hybrids relates to the larger canopy (AF), leaf architecture, plant height, and the higher relative growth rate and efficient use of environmental resources by the crop (Williams et al., 2008). The competition imposed by genetic material is a tool for integrated weed management. Current strategies seek to reduce the use of herbicides, lower the cost and environmental pollution, and produce contaminant-free food (Jha et al., 2017; Tavares et al., 2019; Galon et al., 2019). In this context, developing hybrids presenting competitiveness promotes economic and environmental gains and the possibility of using fewer herbicides.

The average density of 20 volunteer soybean plants m^{-2} with the maize hybrids caused productivity losses ranging from approximately 13 to 36%, values estimated by the hyperbolic equation (Table 1). The maize grain yield loss infested by 3 to 4 m^{-2} volunteer soybean plants was 10% in work by Alms et al. (2016). The average soybean grain loss from self-propelled harvesters is 81.2 kg ha^{-1} (Schanoski et al., 2011). The average weight of 1000 grains is approximately 200 g, which corresponds to 406,000 grains (Câmara, 2015). Therefore, estimating its germination rate at 50% means 203,000 soy plants per hectare or 20.30 plants m^{-2}. This fact illustrates the potential for yield losses in maize crops if volunteer soybean control procedures are inadequate. In this way, reducing losses in the soybean harvest will allow a higher economic return by enabling yield gains for this

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Table 1. Adjustments obtained with the rectangular hyperbola model of Cousens (1985) for grain yield loss by volunteer soybean interference as a function of maize hybrids; NK 422 Viptera3, NK 488 Viptera3, Supremo Viptera 3, Brevant 2A401 PWU, FS 481 PW, and FS 620 PWU in response to the relative explanatory variables. UFFS Erechim/RS.

Relative Explanatory Variable	Parameters[1]		R^2	QMR	F
	i	*a*			
Plant density (DP) of volunteer soybean (m^{-2})					
NK 422 Vip3	5,42	38,62	0,87	104,90	39,87*
NK 488 Vip3	0,95	36,70	0,95	23,77	76,38*
Syn Supremo Vip3	1,90	41,51	0,79	27,60	21,01*
Brevant 2A401 PWU	1,84	68,53	0,76	109,40	52,62*
FS 481 PW	10,76	43,37	0,63	68,71	99,98*
FS 620 PWU	3,65	46,05	0,82	125,90	39,82*
Soybean volunteer ground cover (CS) (%)					
NK 422 Vip3	0,09	35,57	0,81	106,70	44,73*
NK 488 Vip3	0,007	102,30	0,63	18,23	101,20*
Syn Supremo Vip3	0,02	40,58	0,79	18,75	180,45*
Brevant 2A401 PWU	0,05	49,84	0,73	119,10	47,96*
FS 481 PW	0,14	42,97	0,76	78,73	86,61*
FS 620 PWU	0,09	36,04	0,65	171,00	27,78*
Leaf area (AF) of volunteer soybean (cm^2 m^{-2})					
NK 422 Vip3	0,001	36,72	0,88	96,71	49,86*
NK 488 Vip3	0,0003	29,56	0,67	13,25	141,04*
Syn Supremo Vip3	0,0007	34,51	0,95	17,24	196,74*
Brevant 2A401 PWU	0,0002	153,40	0,61	95,61	60,97*
FS 481 PW	0,005	40,74	0,70	95,62	70,43*
FS 620 PWU	0,003	33,52	0,82	166,30	28,71*
Aboveground dry matter (MS) of volunteer soybean (g m^{-2})					
NK 422 Vip3	0,09	34,34	0,92	86,54	56,30*
NK 488 Vip3	0,006	30,39	0,57	19,04	97,12*
Syn Supremo Vip3	0,02	31,27	0,93	18,35	184,55*
Brevant 2A401 PWU	0,02	45,95	0,75	111,00	51,81*
FS 481 PW	0,22	40,42	0,86	59,61	116,00*
FS 620 PWU	0,06	36,20	0,85	135,30	36,42*

[1]*i* e *a*: maize grain yield losses (%) per unit of volunteer soybean when the variable value approaches zero or tends to infinity, respectively; * Significant at p≤0.05.

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crop and reducing the potential losses from its competition with maize.

Analyzing the yield losses, taking into account the AF, showed that the volunteer soybean accumulated 2000 cm^2 m^{-2} of AF, and the materials FS 481 PW and FS620 PWU presented the most significant reductions with 8.03 and 5.09%, respectively, using the values obtained by the equation of the rectangular hyperbola (Table 1). The degree of weed competition with maize depends on the leaf area of the weed. Therefore, the plant density may be directly related to the accumulation of leaf area. Galon et al. (2019) observed that as the alexandergrass appeared in a higher proportion of weed plants of various maize hybrids, the plant showed more AF than the crop and consequently more competitive ability, reducing grain yields.

The results for yield loss of maize hybrids, concerning the percentage of SC and DM, show similarity to that observed for PD and AF (Table 1). Hybrids NK 488 Vip3, Syn Supremo Vip3, and Brevant 2A401 PWU were the most competitive, showing the lowest yield losses. The increased AF, CS, and MS in volunteer soybeans are directly related to DP. This fact helps explain the similarity in productivity losses among the variables evaluated when considering the *i* parameter of each variable studied. Among the factors related to this interference imposed by weeds is competition for environmental resources (water, light, and nutrients), leading to losses in crop productivity (Jha et al., 2017; Tavares et al., 2019; Frandoloso et al., 2020).

In general, considering parameter i, in the average of the four variables analyzed, the most competitive hybrids were: NK 488 Vip3 > Syn Supremo Vip3 > Brevant 2A401 PWU > FS620 PWU > NK 422 Vip3 > FS 481 PW (Table 1). The differences observed between the hybrids may be attributed to the genetic differentiation between them, such as development cycle, plant architecture, leaf area index, the root system volume, the best use of space, or resources availability in the environment, among others, as reported in the literature (Bajwa et al., 2017; Galon et al., 2019). All these characteristics change the degree of maize competition in the presence of volunteer soy plants. It is noteworthy that the productive potential of the hybrids was inversely proportional to their competitive ability. The highest yielding materials in this study probably promote a more allocation of resources to the developing reproductive structures to the detriment of other plant organs that could give it more competitive ability in the presence of volunteer soybeans. Some studies reported that resource allocations are a fundamental aspect of the competition between plant species and are an essential factor that is conditioned to their competitive ability when living together in communities (Carvalho et al., 2011; Cury et al., 2012).

The estimates of parameter a, independent of the explanatory variable, were all less than 100%, except for CS in hybrid NK 488 Vip3 and AF in Brevant 2A401 PWU (Table 1). Thus, it was possible to adequately simulate the maximum yield losses according to the established volunteer soybean densities. However, the two situations where the parameter *a* exceeded 100% of maximum losses may indicate that the density of volunteer soybean plants was too low and/or the highest values are insufficient to produce asymptotic yield loss responses (Cousens, 1985; Agostinetto et al., 2010).

Of all variables analyzed, the best fits to the model corresponded to MS > DP > AF > CS. In addition, it was considered the highest mean values of R^2 and F and the lowest mean value of QMR (Table 1). Thus, the data demonstrate that MS might serve as a substitute for the other variables to estimate maize grain yield losses in the presence of volunteer soybean densities. Similar results to those of the present study came from evaluating the competition of densities or hybrids of maize in coexistence with alexandergrass (Galon et al., 2019; Frandoloso et al., 2020).

The variable DP of volunteer soybeans served for simulating the economic damage level (NDE) values. The choice of this variable occurred since it presented a satisfactory fit to the model, is the most commonly used inference for decision-making in the field since it is easy to obtain, and is also the variable widely used in experiments with this purpose (Vidal et al., 2004; Agostinetto et al., 2010; Galon et al., 2019; Frandoloso et al., 2020).

Successful implementation of volunteer soybean management systems in the maize crop may result from determining the density that exceeds the NDE. The hybrids NK 488 Vip3, Syn Supremo Vip3, and Brevant 2A401 PWU showed the highest NDE values in the simulations performed, having variations from 1.01 to 3.82 plants m^{-2} (Figures 1, 2, 3, and 4). Conversely, the lowest NDE values resulted from NK 422 Vip3 and FS 481 PW, ranging from 0.18 to 1.00 plant m^{-2}. The hybrid FS620 PWU was in an intermediate level of NDE compared to the others.

Comparing the yields of the hybrids, taking into account the lowest (3.98 t ha^{-1}) with the highest (7.09 t ha^{-1}), a difference in NDE of up to 43.82% occurred (Figure 1). Thus, the higher the yield potential of the maize hybrids, the lower the volunteer soybean plant density equals the NDE. This scenario makes it worthwhile to adopt weed control measures even at low densities. Vidal et al. (2004) e Galon et al. (2019) affirm that the NDE of alexandergrass in infesting maize rises as the price of the crop decreases and the cost of control increases. On the other hand, increasing the price of maize reduces the impact of the cost of weed control, achieving a higher economic return with the crop.

The variation of the price paid in the bag of maize was 1.76 times the value of the NDE (Figure 2). The herbicide use compensates when the price paid per bag of maize is lower than the density needed for volunteer soybeans to overcome the NDE. The most competitive hybrids were NK 488 Vip3, Syn Supremo Vip3, and Brevant 2A401 PWU, all showing an NDE higher than 1.79 plants m^{-2} of volunteer soybeans. The higher competition of these

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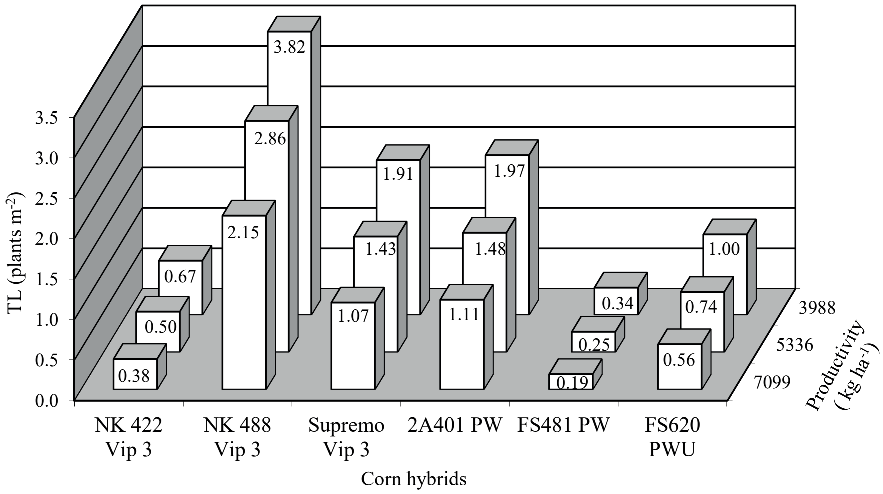

Figure 1. Economic damage level (TL) for maize as a function of grain productivity, volunteer soybean plant densities (m^2) and different hybrids.

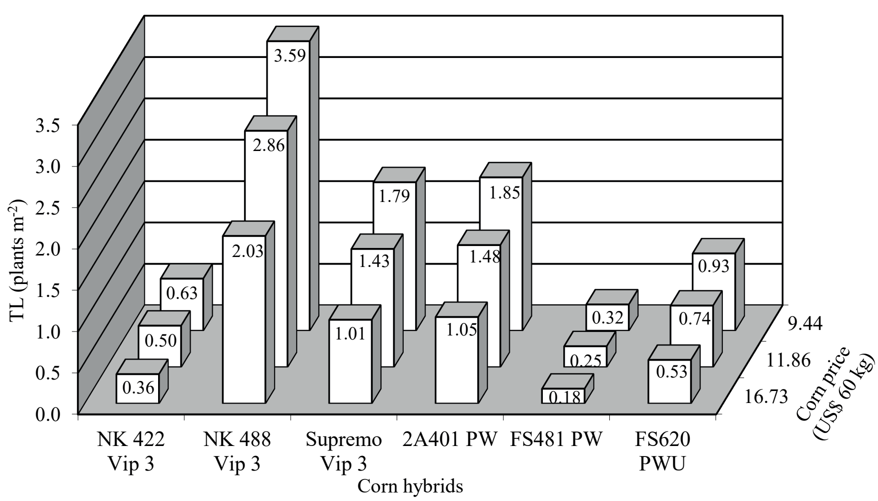

Figure 2. Economic damage level (TL) for maize as a function of maize price, volunteer soybean densities, and different hybrids.

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hybrids, as explained above, is partly due to the genetic differences they present from others, making them have increased competitive ability in the presence of weeds.

Concerning the cost of control of volunteer soybeans, a variation of approximately 40% occurred by comparing the minimum cost with the maximum cost. The higher the cost of the control method, the higher the NDEs and the more volunteer soybean plants m^{-2} it requires to justify control measures (Figure 3). Frandoloso et al. (2020) also reported similar results to the present study but studied the effect of densities of alexandergrass (*Urochloa plantaginea*) in competition with different maize hybrids.

The variation of 80 and 100% in chemical control effectiveness resulted in a change in NDE of approximately 11.03 and 9.90%, respectively (Figure 4). In this way, it becomes clear that the level of control directly influences the NDE. In general, the higher the effectiveness of the herbicide, the lower the NDE, i.e., the smaller number of volunteer soybean plants m^{-2} needed for control measures. When evaluating the efficacy of ammonium glufosinate for the control of alexandergrass in maize, Frandoloso et al. (2020) also reported similar results to those found in the present study, even with different herbicides and weeds in the research.

The NDEs decrease with the increase in grain production, the price per bag of maize, herbicide efficiency, and the reduction in the

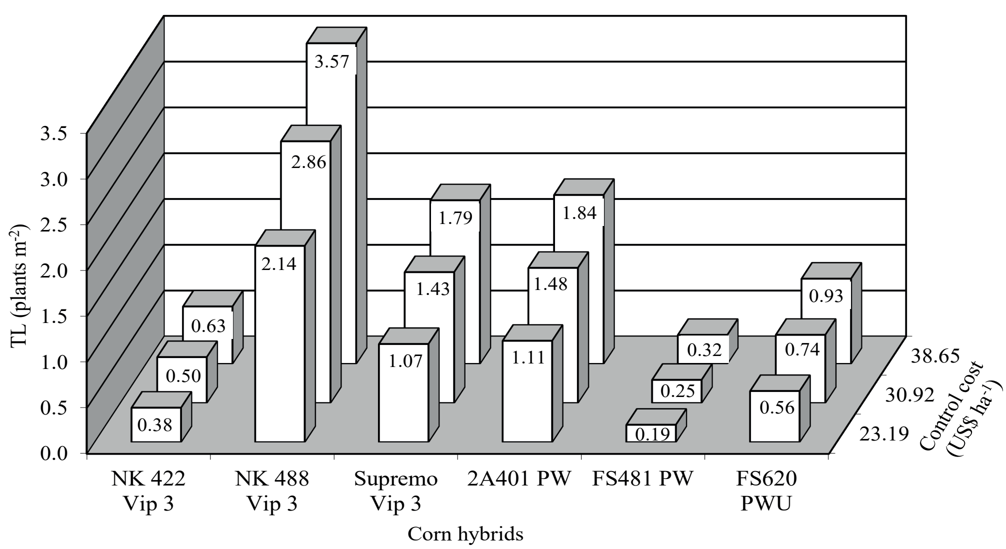

Figure 3. Economic damage level (TL) for maize as a function of control cost, volunteer soybean densities, and different hybrids.

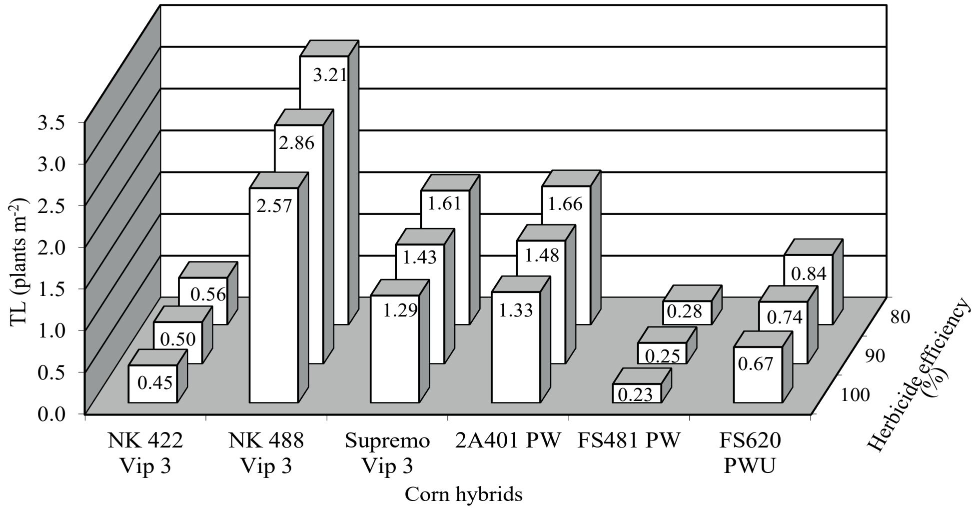

Figure 4. Economic damage level (TL) for maize as a function of herbicide efficiency, volunteer soybean densities, and different hybrids.

cost of control of volunteer soybeans, justifying the adoption of control measures at lower weed densities. The use of NDE as a tool for weed management must be associated with good agricultural practices for maize. Its adoption is only justified in crops that use crop rotation, adequate plant arrangement, more competitive hybrids, adequate sowing times, soil fertility correction, and others. Although the control of volunteer soybeans is mandatory, in determining periods of the year that coincide with the development of maize, the use of NDE can help producers make decisions for assuring management.

Conclusions

Maize hybrids NK 488 Vip3, Syn Supremo Vip3, and Brevant 2A401 PWU demonstrated higher competitiveness when infested by volunteer soybean.

The highest NDE values ranged from 1.01 to 3.82 plants m^{-2} for maize hybrids NK 488 Vip 3, Syn Supremo Vip 3, and Brevant 2A401 PWU showed the highest competitive ability, thus tolerating higher volunteer soybean densities.

Maize hybrids NK 422 Vip 3, FS 481 PW, and FS 620 PWU demonstrate the lowest NDE value ranging from 0.18 to 1.00 plants m^{-2}, being less competitive in the presence of volunteer soybean.

NDEs decrease as grain yields increase,

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the price of a bag of maize increases, and the cost of controlling volunteer soybeans and herbicide efficiency decreases.

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