DOI: 10.1590/1808-1657000862019

Weed management in glyphosate-resistant maize*

Manejo de plantas daninhas em milho resistente ao glifosato

Maicon Rodrigues da Silva[1] (https://orcid.org/0000-0003-0838-6991)
Leandro Galon[1]** (https://orcid.org/0000-0002-1819-462X)
Emanuel Rodrigo de Oliveira Rossetto[1] (https://orcid.org/0000-0002-5159-8175)
Alexandre Ferreira da Silva[2] (https://orcid.org/0000-0002-4877-2830)
Emanuel Luis Favretto[1] (https://orcid.org/0000-0003-0060-4093)
Leonardo Brunetto[1] (https://orcid.org/0000-0002-8252-6908)
Alessandra Gallina[1] (https://orcid.org/0000-0001-9697-7286)
Antônio Marcos Loureiro da Silva[1] (https://orcid.org/0000-0001-7198-8616)
Rodrigo José Tonin[1] (https://orcid.org/0000-0003-3583-4243)

ABSTRACT: The application of glyphosate associated with other herbicides is an important alternative for weed control in maize, to increase control spectrum and to minimize problems with resistance and tolerance from some species to the product. The objective of this work was to evaluate the efficacy, selectivity and effects on the grain yield components of glyphosate-resistant maize as a function of its application, associated or not with other pre- and postemergence herbicides. The design used was randomized blocks with four replications. Treatments consisted in the use of glyphosate combined with the herbicides: atrazine, [atrazine + simazine], [atrazine + oil], [atrazine + S-metolachlor], applied pre- and/or postemergence and [nicosulfuron + mesotrione] only postemergence, plus two controls, one weeded and one infested. The evaluated variables were maize phytotoxicity, weed control, ear insertion height, number of rows per ear, number of grains per row, one thousand grain mass and grain yield. Herbicide treatments caused low phytotoxicity to maize, less than 6%; control greater than 88, 95 and 95% for alexandergrass, turnip and sunflower, respectively, and did not affect grain yield components. The tested herbicides are selective to the hybrid Forseed 2A521 PW and effective in weed control. Weed control with weeding or herbicide increased maize Forseed 2A521 PW yield by 43%. The association of glyphosate with pre- or postemergence herbicides increased maize grain yield by approximately 14%.

KEYWORDS: association of herbicides; *Brachiaria*; *Raphanus sativus*; *Helianthus annuus*.

RESUMO: O uso de glifosato associado com outros herbicidas torna-se uma alternativa importante para o manejo de plantas daninhas infestantes do milho, pois ele aumenta o espectro de controle, minimiza problemas com resistência e tolerância de plantas daninhas ao herbicida. O objetivo deste trabalho foi estudar a eficiência, a seletividade e os efeitos nos componentes de rendimento de grãos do milho resistente ao glifosato pelo uso dessa substância associada ou não a outros herbicidas aplicados em pré- e pós-emergência. O experimento foi instalado em delineamento de blocos ao acaso, com quatros repetições. Os tratamentos consistiram na utilização do glifosato em combinação com os herbicidas: atrazina, [atrazina + simazina], [atrazina + óleo], [atrazina + S-metolacloro], aplicados em pré- e/ou pós-emergência e o [nicosulfuron + mesotriona] somente em pós-emergência, além das testemunhas capinada e infestada. Avaliaram-se as variáveis: fitotoxicidade ao milho, controle de plantas daninhas, altura de inserção de espigas, número de fileiras e de grãos por espiga, peso de mil grãos e a produtividade de grãos. Os herbicidas ocasionaram baixa fitotoxicidade ao milho, inferior a 6%, controle superior a 88, 95 e 95% para papuã, nabo e girassol, respectivamente, e não influenciaram negativamente nos componentes relacionados ao rendimento de grãos da cultura. Os herbicidas testados são seletivos ao híbrido Forseed 2A521 PW e efetivos no controle de papuã, nabo e girassol. O manejo das plantas daninhas com capina ou herbicidas proporcionou aumento de cerca de 43% na produtividade de grãos do híbrido de milho Forseed 2A521 PW. O uso de glifosato em mistura de tanque com herbicidas aplicados em pré- ou pós-emergência incrementou, aproximadamente, 14% a produtividade de grãos de milho.

PALAVRAS-CHAVE: associação de herbicidas; *Brachiaria*; *Raphanus sativus*; *Helianthus annuus*.

[1]Universidade Federal da Fronteira Sul – Curso de Agronomia/Programa de Pós-Graduação em Ciência e Tecnologia Ambiental – Laboratório Manejo Sustentável dos Sistemas Agrícolas – Erechim (RS), Brazil.
[2]Empresa Brasileira de Pesquisa Agropecuária – Embrapa Milho e Sorgo – Sete Lagoas (MG), Brazil.
*This paper is part of the undergraduate thesis of the first author.
**Corresponding author: leandro.galon@uffs.edu.br
Received on: 12/20/2019. Accepted on: 09/20/2020

INTRODUCTION

Maize is one of the main crops sown in Brazil, it is used in human and animal feed, being cultivated throughout the national territory. The sown area in 2017/2018 crop was approximately 17.3 million hectares, with a production of about 90 million tonnes (CONAB, 2019). The three largest maize producing countries in the world nowadays are the United States, China and Brazil (FAO, 2019). Despite the large volume of grains produced, the average yield is low, ranging from 4 to 5 $t \cdot ha^{-1}$. Among the factors that favor the low productivity of maize grains, the inadequate management of the weed community can be mentioned, because these weeds compete for the available resources in the environment, besides being hosts of insects and diseases or even release allopathic substances that interfere in the growth and development of the crop. The absence of control may cause losses higher than 80% in crop yield (GALON et al., 2018a).

The chemical control method, with the use of herbicides, has stood out for its efficiency, agility and for the lower cost, when compared to other ways of weed management in crops (TIMOSSI; FREITAS, 2011). The introduction of glyphosate-resistant (GR) crops initiated with the commercial release of soybean in the 2005/2006 crop, of cotton and maize in the 2010/2011 crop, which promoted great changes in the chemical control strategies of these crops (CTNBIO, 2019). Due to the ample spectrum of action, selectivity, low cost and efficacy in the control of more developed weeds, glyphosate has become the main molecule used for the management of weed species in genetically modified crops (SILVA et al., 2018).

However, the continuous application of glyphosate in production systems has been increasing the selection pressure, which favors the emergence of species with resistance or tolerance to this product. The wide dissemination of these plants in the national territory has contributed to the loss of effectiveness of this technology (WESTWOOD et al., 2018; LUCIO et al., 2019).

Therefore, the use of herbicides in mixture with glyphosate becomes an important technique in the management of weed species with resistance or tolerance to this product. In Brazil, there are nine cases of plants resistant to glyphosate (HEAP, 2019) and around ten tolerant species (CONCENÇO et al., 2014). There are 40 active ingredients registered for the control of weeds of the maize crop in Brazil (MAPA, 2019). Among these herbicides, there are photosynthesis inhibitors in photosystem II, cell division, pigment inhibitors and inhibitors of acetolactate synthase (ALS), which stand out as important alternatives to assist in the management of resistant biotypes and glyphosate-tolerant species in maize crop. Studies evaluating the efficacy of the herbicide mixture on the weed community and the selectivity of the crop are extremely important for the elaboration of more effective control strategies.

The use of glyphosate in mixture with herbicides from different mechanisms of action may be an alternative to reduce the selection of new cases of resistant weeds and manage those plants that already demonstrate resistance to herbicides (AGOSTINETTO; VARGAS, 2014). Many cases of resistance in Brazil in species belonging to the genus *Urochloa* and *Digitaria*, to ALS and photosystem II inhibitors were reported, and it is likely that there are biotypes with resistance to enol-pyrovyl-shikimate-3-phosphate synthase (EPSPS) inhibitor herbicides (AGOSTINETTO; VARGAS, 2014). The association of herbicides in tanks or sequential applications are created to increase the spectrum, thus improving weed management, which is also an important technique for the control of biotypes that present resistance or tolerance, especially when two or more mechanisms are applied in these mixtures (AGOSTINETTO; VARGAS, 2014).

The herbicides used in an associated way cause a high level of control, demonstrating efficiency in the management and low phytotoxicity to maize (CARVALHO et al., 2010). The association of atrazine + nicosulfuron, when applied in initial postemergence of weeds, proved to be an interesting option for the control of alexandergrass (*Urochloa plantaginea*), keeping maize free of weeds throughout the development cycle (GALON et al., 2010).

According to GAZZIERO (2015), in 73% of the situations that occur mixtures in tanks, producers claim to observe symptoms of phytotoxicity on crops. Therefore, preliminary studies evaluating possible harmful effects on crops and antagonism in the control of the weed community are extremely important for the productive sector.

The hypothesis is that the mixture of herbicides in tank or sequential applications with glyphosate improves the control efficacy of the weed community and does not interfere in the selectivity of the maize hybrid Forseed 2A521 PW. The objective of this work was to study the efficiency, selectivity and effects on grain yield components of glyphosate-resistant maize by its use associated or not with other herbicides applied in pre- and postemergence.

MATERIAL AND METHODS

An experiment was installed in the experimental area of the Federal University of the Southern Frontier (UFFS), Campus Erechim, from October to April of the 2018/19 crop. The soil of the area is classified as typical aluminum-ferric red latosol (EMBRAPA, 2013). The experimental design used was the randomized blocks, replicated four times. The treatments are described in Table 1, together with the doses and modalities of applications.

Maize was sown on 10/25/2018 in a no-tillage system, and the desiccation with glyphosate was made 30 days before sowing, which presented average of 5.7 t·ha^{-1} of dry mass that was used as winter cover composed by the species of black oat + turnip in mixture. A chemical analysis was used to correct soil fertility, following the technical recommendations for maize crop destined to grain (NRS-SBCS; CQFS-RS/SC, 2016). In the sowing furrow, 433 kg·ha^{-1} of the formula 05-30-15 of N-P-K were used as base fertilization, followed by the application of top-dressing nitrogen (139.5 kg·ha^{-1} of N) at V6 stage, in the urea form (310 kg·ha^{-1}). Each experimental unit had a total area of 5 × 4 (20 m²) and six rows of the Forseed 2A521 PW maize hybrid, resistant to glyphosate and glufosinate-ammonium. The spacing used between maize lines was 50 cm and sowing density was 3.65 seeds per linear meter, resulting in a density of about 73,000 plants per hectare.

The herbicides were applied with the aid of a CO_2 pressurized costal sprayer, equipped with a bar connected with four spray nozzles of the type DG110.02, at a distance of 50 cm from each other, maintaining constant pressure of 210 kPa and displacement speed of 3.6 km·h^{-1}, which caused flow rate of 150 L·ha^{-1}.

The environmental conditions observed at the time of application of the treatments in pre- and postemergence of maize and weeds are arranged in Table 2, as well as the monthly rainfall (mm) and the average temperature in the period of the experiment (Fig. 1). Right after maize sowing, applications of preemergent herbicides were made. The postemergent herbicides were applied when the maize was about the fifth (V5) and sixth (V6) completely expanded leaf; in this moment, the eudicotyledons weeds presented between 1 to 2 pairs of leaves and the monocotyledons, the emission of the first tiller. The existing weeds in the experimental area were turnip/radish (*Raphanus sativus*), alexandergrass (*U. plantaginea*) and sunflower (*Helianthus annuus*) at average densities, respectively, of 33, 193, 12 plants·m^{-2} originating from the soil seed bank.

At 7, 14 and 21 days after the application of the postemergent treatments (DAT), the variables phytotoxicity of maize plants and control of alexandergrass, turnip and sunflower were evaluated. Phytotoxicity and control were evaluated by assigning percentage scores, being zero (0%) the absence of injuries or weed control and one hundred (100%) for weed control or the death of maize plants (VELINI et al., 1995).

In the preharvest of the crop, 10 ears of maize were randomly collected in each experimental unit to determine the height of ear insertion (HEI), the number of rows of grains per ear (NRE) and the number of grains per row (NGR). The HEI was measured using a ruler graduated in centimeters,

Table 1. Treatments used in the experiment, respective doses and time of application for weed control in the maize hybrid Forseed 2A521 PW. UFFS Erechim/RS, 2018/19.

Treatments	Doses (g·ha^{-1}) a.i.	Doses L·ha^{-1}	Adjuvant 0.5% v/v	Application mode[1]
Infested control	...	...	...	...
Weeded control	...	...	...	...
Atrazine/glyphosate	2500+1440	6.00+3.00	...	Pre/Post
[Atrazine + simazine]/glyphosate	1500+1500+1440	6.00+3.00	...	Pre/Post
[Atrazine + oil]/glyphosate	2400+1440	6.00+3.00	...	Pre/Post
S-metolachlor/glyphosate	1680+1440	1.75+3.00	...	Pre/Post
[Atrazine + S-metolachlor]/glyphosate	1480+920+1440	4.00+3.00	...	Pre/Post
Glyphosate	1440	3.00	...	Post
Glyphosate + atrazine	1440+2500	3.00+6.00	Assist	Post
Glyphosate + [atrazine + oil]	1440+2400	3.00+6.00	...	Post
Glyphosate + S-metolachlor	1440+1680	3.00+1.75	Assist	Post
Glyphosate + [atrazine + simazine]	1440+1500+1500	3.00+6.00	Assist	Post
Glyphosate + [atrazine + S-metolachlor]	1440+1480+920	3.00+4.00	Assist	Post
Glyphosate + [nicosulfuron + mesotrione]	1440+23.4+109.4	3.00+0.25	Nimbus	Post

[1] Pre/Post: Herbicides applied in pre- and postemergence of weeds and maize, respectively.

Table 2. Environmental conditions at the time of application of treatments in pre- and postemergence of maize and weeds. UFFS Erechim/RS 2018/19.

Application mode	Luminosity (%)	Temperature (°C)	Reactive humidity (%)	Soil conditions	Wind speed (km·h^{-1})
Preemergence	50	23	63	friable	6.8
Postemergence	100	16	40	humid	2.0

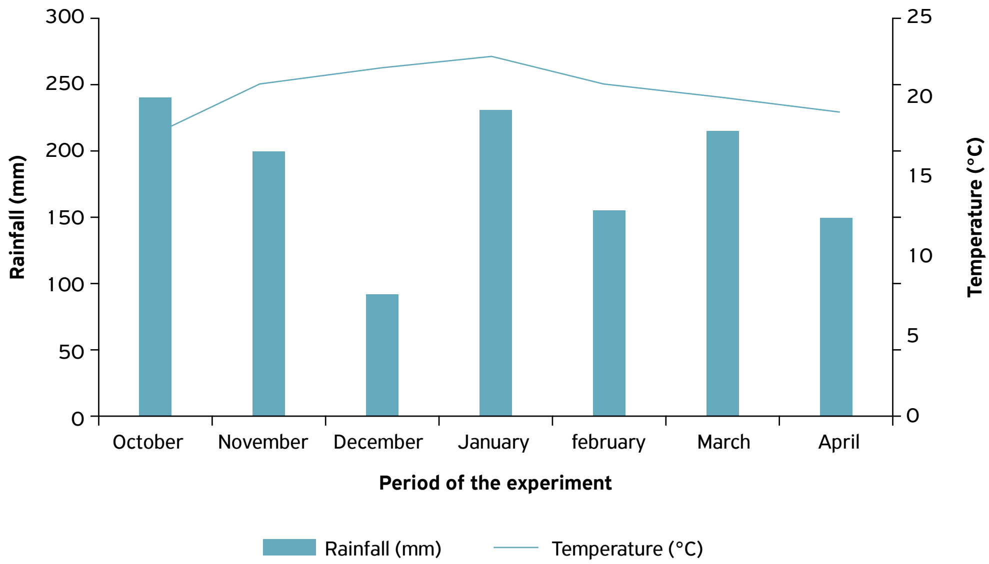

Figure 1. Monthly rainfall (mm) and average temperature in the period of the experiment. Erechim/RS, 2018/19.

from the base of the plant to the insertion of the first ear of maize plants. The NRE and NGR were determined by counts.

When the corn kernels reached 20% humidity, the ears were harvested in a useful area of 6 m^2 per experimental unit, and, subsequently, the threshing was carried out with a plot trailer. The thousand grains weight (PMG) (g) was determined by counting 8 samples with 100 grains in each replication, and was subsequently weighed on an analytical scale. Grain moisture was adjusted to 13% for the determination of the PMG and grain yield, which was extrapolated to $kg{\cdot}ha^{-1}$.

The data were submitted to normality and additivity tests, and after proving the normality of the errors, the analysis of variance was performed by the F-test, being significant, the Scott–Knott test ($p \leq 0.05$) was applied.

RESULTS AND DISCUSSION

Regarding phytotoxicity, at 7 DAT, glyphosate was the only herbicide that did not caused symptoms of intoxication, the others presented similar levels of injuries, with values lower than 6% (Table 3). At 14 DAT, symptoms remained low, with the highest values caused by the mixture of glyphosate with [atrazine + oil], [atrazine + simazine] and [atrazine + S-metolachlor] applied in postemergence, but with indices lower than 5% (Table 3). At this time of evaluation, the treatments used in preemergence, S-metolachlor + glyphosate and [atrazine + S-metolachlor] + glyphosate and in postemergence S-metolachlor + glyphosate and glyphosate + [nicosulfuron + mesotrione] were the second group of herbicides that caused the highest levels of phytotoxicity to maize. At 21 DAT, the crop no longer presented injuries resulting from the use of herbicides, in other words, the plants recovered from the initial symptoms (Table 3). This fact demonstrates the high selectivity of the treatments to maize, even when applied in mixture with glyphosate. The results obtained in the present study were similar to those observed by BASSO et al. (2018), when they found low levels of phytotoxicity in maize by applying the herbicide mixture with glyphosate in pre- or postemergence.

The association of herbicides with different mechanisms of action is a recurrent practice that aims to increase the effectiveness of control in the weed community (VARGAS et al., 2013), especially in problematic plants, resistant and tolerant to glyphosate. However, this practice should be carried out with caution, because some researches show the possibility of antagonistic effects, and this fact impairs its effectiveness of control and selectivity to the crop (GOULART et al., 2012).

All herbicides showed good levels of control for alexandergrass, regardless of the evaluation time, having control greater than 88% (Table 4). At 7 DAT, control levels were higher than 91%, and the highest efficacies were observed with the preemergence applications of atrazine, [atrazine + simazine], S-metolachlor, [atrazine + S-metolachlor] followed by the use of glyphosate in postemergence. The second most effective group in the control of alexandergrass involved: preemergence application of [atrazine + oil] + glyphosate in postemergence and the use of glyphosate, atrazine, [atrazine + oil], S-metolachlor, [atrazine + simazine], [atrazine + S-metolachlor] and [nicosulfuron + mesotrione] all associated with glyphosate in postemergence of the species.

The application of preemergent herbicides becomes an important alternative to reduce emergence flow and/or to slow weed growth, which increases the efficacy of postemergent herbicides (DREHMER et al., 2015). This herbicide positioning strategy has been mainly used in areas with problems of resistant or

Table 3. Phytotoxicity (%) to Forseed 2A521 PW hybrid maize due to applications of herbicides associated with glyphosate. UFFS Erechim/RS, 2018/19.

Treatments	Application mode	Phytotoxicity to maize (%)		
		7 DAT[1]	14 DAT	21 DAT
Infested control	---	0.00 b[2]	0.00 c	0.00 ns
Weeded control	---	0.00 b	0.00 c	0.00
Atrazine/glyphosate	Pre/Post	3.75 a	0.00 c	0.00
[Atrazine + simazine]/glyphosate	Pre/Post	4.25 a	0.00 c	0.00
[Atrazine + oil]/glyphosate	Pre/Post	3.25 a	0.00 c	0.00
S-metolachlor/glyphosate	Pre/Post	4.25 a	3.25 b	0.00
[Atrazine + S-metolachlor]/glyphosate	Pre/Post	4.00 a	3.00 b	0.00
Glyphosate	Post	0.00 b	0.00 c	0.00
Glyphosate + atrazine	Post	3.25 a	0.00 c	0.00
Glyphosate + [atrazine + oil]	Post	4.25 a	4.00 a	0.00
Glyphosate + S-metolachlor	Post	4.50 a	3.00 b	0.00
Glyphosate + [atrazine + simazine]	Post	5.00 a	5.00 a	0.00
Glyphosate + [atrazine + S-metolachlor]	Post	4.50 a	5.00 a	0.00
Glyphosate + [nicosulfuron + mesotrione]	Post	5.25 a	3.00 b	0.00
CV (%)		37.2	40.43	0.00

[1] Days after application of the treatments. [2] Means followed by the same letters in the column do not differ by the Scott-Knott test at $p \leq 0.05$.

Table 4. Control (%) of *U. plantaginea* weed of Forseed 2A521 PW maize hybrid as a function of herbicide applications associated with glyphosate. UFFS, Erechim, RS. 2018/19.

Treatments	Application mode	Control of alexandergrass (%)		
		7 DAT[1]	14 DAT	21 DAT
Infested control	---	0d[2]	0b	0e
Weeded control	---	100a	100a	100a
Atrazine/glyphosate	Pre/Post	97b	100a	88d
[Atrazine + simazine]/glyphosate	Pre/Post	98b	100a	90d
[Atrazine + oil]/glyphosate	Pre/Post	96c	100a	90d
S-metolachlor/glyphosate	Pre/Post	97b	100a	90d
[Atrazine + S-metolachlor]/glyphosate	Pre/Post	97b	100a	90d
Glyphosate	Post	95c	100a	89d
Glyphosate + atrazine	Post	94c	100a	96b
Glyphosate + [atrazine + oil]	Post	91c	100a	93c
Glyphosate + S-metolachlor	Post	96c	100a	96b
Glyphosate + [atrazine + simazine]	Post	96c	100a	97b
Glyphosate + [atrazine + S-metolachlor]	Post	92c	100a	95c
Glyphosate + [nicosulfuron + mesotrione]	Post	95c	100a	94c
CV (%)		2.52	0.28	3.49

[1] Days after application of the treatments. [2] Means followed by the same letters in the column do not differ by the Scott-Knott test at $p \leq 0.05$.

tolerant plants to glyphosate (MELO et al., 2012). At 14 DAT, all herbicides showed results similar to those observed in the weeded control (Table 4). At 21 DAT, the efficacy of the treatments was lower than the efficacy of the weeded control, but all presented control level close to or greater than 90% (Table 4).

Regarding turnip control, the results show similar levels of efficacy when comparing the weeded control and herbicide treatments, from 7 to 14 DAT, except for the application of glyphosate, which showed efficacy of 98%; however, it remained among the best control groups (Table 5). At 21 DAT, all herbicide treatments showed control levels higher than 95%. The combination of glyphosate with atrazine, [atrazine + oil], [atrazine + simazine], [atrazine + S-metolachlor] and [nicosulfuron + mesotrione], used in postemergence, showed similar efficacy to the weeded control. The mixture of herbicides with different mechanisms of action stands out as an important weed management method, aiming to reduce the selection pressure of resistant biotypes and expand the control spectrum (BRESSANIN et al., 2015).

The results demonstrate that all herbicide treatments presented levels of sunflower control similar to the weeded control, regardless of the evaluation periods, being higher than 95% (Table 6). The control of weeds originating from harvest grain losses, such as sunflower, is a necessary practice, because when these plants develop during the establishment of the crop of economic interest, they can cause losses of yield due to competition for the environmental resources, besides to hosting insects and diseases (SILVA et al., 2018).

To be considered efficient, an herbicide needs to show efficacy higher than 80% in the control of a certain weed species (OLIVEIRA et al., 2009). Thus, it is denoted that all tested herbicides presented satisfactory control levels, regardless of the evaluation time.

The high rate of control of the weeds can be attributed to the application of glyphosate in postemergence due to the fact that all three species are susceptible to this product. However, mixtures with herbicides belonging to other mechanisms of action help the nonemergence of glyphosate-resistant biotypes and aid to control more effectively the tolerant ones present in maize crop or even keep the crop clean in the initial development period. The adequate control of the weed community during the initial period of maize establishment has a fundamental importance for the crop express its yield potential. Studies indicate that the critical period of weed interference on maize is between 11 and 32 days after crop emergence (GALON et al., 2008; 2018a). During this period, the competition between weeds and maize should be minimized, mainly with aggressive species such as alexandergrass, whose lack of control can cause a reduction in crop grain yield of up to 98% (GALON et al., 2008; 2018b).

The treatments did not influence the HEI, NRE and PMG (Table 7). Studies show that phytotoxic effects may influence crop yield components (FELISBERTO et al., 2017; BASSO et al., 2018; GALON et al., 2018b). However, this behavior may be related to several factors, such as cultivar or hybrid characteristics, formulation, dose and time of herbicide application, crop management, and climatic conditions (VALDERRAMA et al., 2011). The number of grains per row (NFG) and yield (PROD) showed differences only for the infested control. When comparing the mean of herbicide treatments and the infested control, an increase of approximately 43% was observed. The grain yield of maize increased by 14%, when comparing the averages of tank mixtures of the products, applied in pre- and postemergence, with glyphosate in isolated use. Thus, it is clear that the associations of herbicides to glyphosate applied in pre- or postemergence improve its efficacy in controlling weeds in maize, which reflects in higher grain yield and also facilitates the management of glyphosate resistant or tolerant weeds. BASSO et al. (2018) reported results similar to these when they found higher maize

Table 5. Control (%) of turnip – *R. sativus* L. weed of Forseed 2A521 PW maize hybrid as a function of herbicide applications associated with glyphosate. UFFS, Erechim, RS. 2018/19.

Treatments	Application mode	Control of turnip (%)		
		7 DAT[1]	14 DAT	21 DAT
Infested control	---	0b[2]	0c	0c
Weeded control	---	100a	100a	100a
Atrazine/glyphosate	Pre/Post	100a	100a	97b
[Atrazine + simazine]/glyphosate	Pre/Post	100a	100a	97b
[Atrazine + oil]/glyphosate	Pre/Post	100a	100a	95b
S-metolachlor/glyphosate	Pre/Post	98a	100a	97b
[Atrazine + S-metolachlor]/glyphosate	Pre/Post	100a	100a	95b
Glyphosate	Post	90a	98b	96b
Glyphosate + atrazine	Post	97a	100a	100a
Glyphosate + [atrazine + oil]	Post	99a	100a	100a
Glyphosate + S-metolachlor	Post	96a	99a	96b
Glyphosate + [atrazine + simazine]	Post	96a	99a	99a
Glyphosate + [atrazine + S-metolachlor]	Post	99a	100a	100a
Glyphosate + [nicosulfuron + mesotrione]	Post	96a	100a	100a
CV (%)		4.76	0.59	3.27

[1] Days after application of the treatments. [2] Means followed by the same letters in the column do not differ by the Scott–Knott test at $p \leq 0.05$.

Table 6. Control (%) of sunflower – *H. annuus* weed of Forseed 2A521 PW maize hybrid as a function of herbicide applications associated with glyphosate. UFFS Erechim/RS, 2018/19.

Treatments	Application mode	Control of sunflower (%)		
		7 DAT[1]	14 DAT	21 DAT
Infested control	---	0b[2]	0b	0b
Weeded control	---	100a	100a	100a
Atrazine/glyphosate	Pre/Post	100a	100a	95a
[Atrazine + simazine]/glyphosate	Pre/Post	100a	100a	97a
[Atrazine + oil]/glyphosate	Pre/Post	100a	100a	98a
S-metolachlor/glyphosate	Pre/Post	100a	100a	97a
[Atrazine + S-metolachlor]/glyphosate	Pre/Post	100a	100a	97a
Glyphosate	Post	100a	100a	96a
Glyphosate + atrazine	Post	100a	100a	99a
Glyphosate + [atrazine + oil]	Post	100a	100a	100a
Glyphosate + S-metolachlor	Post	100a	100a	98a
Glyphosate + [atrazine + simazine]	Post	100a	100a	99a
Glyphosate + [atrazine + S-metolachlor]	Post	100a	100a	100a
Glyphosate + [nicosulfuron + mesotrione]	Post	100a	100a	98a
CV (%)		0.28	0.28	3.51

[1] Days after application of the treatments. [2] Means followed by the same letters in the column do not differ by the Scott–Knott test at $p \leq 0.05$.

Table 7. Ear insertion height (HEI, m), number of rows per ear (NRE), number of grains per row (NGR), mass of one thousand grains (MTG, g) and grain yield (PROD, kg·ha^{-1}) of Forseed 2A521PW maize hybrid, as a function of the application of herbicides associated with glyphosate. UFFS Erechim/RS, 2018/19.

Treatments	Application mode	Maize yield components				
		HEI	NRE	NGR	MTG	PROD
Infested control	---	1.08^{ns}	14.30^{ns}	23.25b[1]	350.95^{ns}	4954.77b
Weeded control	---	0.99	14.80	29.65a	387.77	9792.49a
Atrazine/glyphosate	Pre/Post	1.02	13.80	27.95a	354.33	9135.71a
[Atrazine + simazine]/glyphosate	Pre/Post	1.02	14.30	27.60a	354.09	8864.66a
[Atrazine + oil]/glyphosate	Pre/Post	1.04	15.10	31.20a	375.82	9296.40a
S-metolachlor/glyphosate	Pre/Post	1.00	14.10	29.40a	362.78	8910.42a
[Atrazine + S-metolachlor]/glyphosate	Pre/Post	1.00	14.20	29.70a	379.56	7596.58a
Glyphosate	Post	0.96	13.70	28.95a	367.24	7571.37a
Glyphosate + atrazine	Post	1.02	14.80	28.00a	367.37	8736.40a
Glyphosate + [atrazine + oil]	Post	1.00	14.40	29.27a	370.75	9133.12a
Glyphosate + S-metolachlor	Post	1.02	15.00	28.70a	368.69	8250.52a
Glyphosate + [atrazine + simazine]	Post	1.00	13.90	30.55a	362.42	9488.51a
Glyphosate + [atrazine + S-metolachlor]	Post	0.98	14.10	30.20a	361.13	8600.21a
Glyphosate + [nicosulfuron + mesotrione]	Post	1.01	14.40	29.20a	381.13	8360.13a
CV (%)		4.79	5.12	8.94	6.74	12.96

^{ns}Not significant at $p \leq 0.05$. [1] Means followed by the same letters in the column do not differ by the Scott–Knott test at $p \leq 0.05$.

grain yields when glyphosate was associated with other herbicides, either in pre- or postemergence applications.

The low grain yield of the infested control (Table 7) reinforces the importance of adequate weed management; therefore, the crop can express its full productive potential. All herbicide applications were equal to the weeded control, surpassing the national average productivity, 5,488 kg·ha^{-1}, for the 2017/18 agricultural year (CONAB, 2019).

CONCLUSIONS

All herbicide treatments showed to be selective to the hybrid Forseed 2A521 PW, and present high efficacy of control of alexandergrass, turnip and sunflower, not causing yield losses in the crop.

The association of glyphosate with other herbicides applied in pre- or post-emergence increased maize grain yield by approximately 14% when compared to the use of glyphosate in isolation.

Weed control with weeding or herbicides increased maize grain yield by about 43%.

ACKNOWLEDGEMENTS: Not applicable

FUNDING: Conselho Nacional de Desenvolvimento Científico e Tecnológico (grants no: 307291/2016-2; 406221/2016-2; 306927/2019-50); Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul (grants no: 19/2551-0000874-0; 842-25.51/13-4); Financiadora de Estudos e Projetos (grant no 0752/13).

CONFLICTS OF INTEREST: All authors declare that they have no conflict of interest.

ETHICAL APPROVAL: Not applicable.

AVAILABILITY OF DATA AND MATERIAL: The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

AUTHORS' CONTRIBUTIONS: Conceptualization: Galon, L.; Silva, A.F.; Favretto, E.L.; Brunetto. Data curation: Silva, M.R..; Galon, L.; Rosseto, E.R.O. Formal analysis: Silva, M.R..; Galon, L.; Rosseto, E.R.O. Funding acquisition: Silva, M.R..; Galon, L.; Rosseto, E.R.O. Investigation: Silva, M.R..; Galon, L.; Rosseto, E.R.O. Methodology: Silva, M.R..; Galon, L.; Rosseto, E.R.O. Project administration: Silva, A.F.; Favretto, E.L.; Brunetto, L. Resources: Silva, A.F.; Favretto, E.L.; Brunetto, L. Supervision: Silva, A.F.; Favretto, E.L.; Brunetto, L. Validation: Silva, A.F.; Favretto, E.L.; Brunetto, L. Visualization: Silva, A.F.; Favretto, E.L.; Brunetto, L. Writing – original draft: Gallina, A.; Silva, A.L.M.; Tonin, J.R. Writing – review & editing: Gallina, A.; Silva, A.L.M.; Tonin, J.R.

REFERENCES

AGOSTINETTO, D.; VARGAS, L. *Resistência de plantas daninhas a herbicidas no Brasil*. Pelotas: UFPel, 2014. 398p.

BASSO, F.J.M.; GALON, L.; FORTE, C.T.; AGAZZI, L.R.; NONEMACHER, F.; PERIN, G.F.; FIABANI, R.C.; WINTER, F.L. Manejo de plantas daninhas em milho RR® com herbicidas aplicados isoladamente ou associados ao glyphosate. *Revista de Ciências Agroveterinárias*, Lages, v.17, n.2, p.148-157, 2018. http://dx.doi.org/10.5965/223811711722018148.

BRESSANIN, F.N.; GIANCOTTI, P.R.F.; NETO JAYME, N.; AMARAL, C.L.; ALVES, P.L.C.A. Eficácia de herbicidas aplicados isolados em pré e pós-emergência no controle de mucuna-preta. *Revista Brasileira de Ciências Agrárias*, Recife, v.10, n.3, p.426-431, 2015. https://doi.org/10.5039/agraria.v10i3a5337

CARVALHO, F.T.; MORETTI, T.B.; SOUZA, P.A. Eficácia e seletividade de associações de herbicidas utilizados em pós-emergência na cultura do milho. *Revista Brasileira de Herbicidas*, Londrina, v.9, n.2, p.35-41, 2010. https://doi.org/10.7824/rbh.v9i2.79

COMISSÃO TÉCNICA NACIONAL DE BIOSSEGURANÇA (CTNBIO). 2019. Available from: http://ctnbio.mctic.gov.br/processo-de-ogm. Access on: 15 Dec. 2019.

COMPANHIA NACIONAL DE ABASTECIMENTO (CONAB). *Acompanhamento da Safra Brasileira de Grãos*. 2019. Available from: https://www.conab.gov.br/info-agro/safras/serie-historica-das-safras. Access on: 15 Dec. 2019.

CONCENÇO, G.; GALON, L.; FERREIRA, E.A.; SILVA, A.A. Tolerância de plantas daninhas a herbicidas. In: SILVA, A.A. *et al. O que os engenheiros agrônomos devem saber para orientar o uso de produtos fitossanitários*. Viçosa: UFV, 2014. 564p.

DREHMER, M.H.; ZAGONEL, J.; FERREIRA, C.; SENGER, M. Eficiência de herbicidas aplicados em pré-emergência para o controle de *Digitaria insularis* na cultura do feijão. *Revista Brasileira de Herbicidas*, Londrina, v.14, n.2, p.148-154, 2015. https://doi.org/10.7824/rbh.v14i2.395

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA (EMBRAPA). *Sistema brasileiro de classificação de solos*. Brasília: Embrapa Solos, 2013. 353p.

FELISBERTO, P.A.C.; FELISBERTO, G.; RAMOS, A.R.; TIMOSSI, P.C. Maize crop phytotoxicity in response to sub-doses of sulfometuron-methyl. *Planta Daninha*, Viçosa, v.35, e017166504, 2017. https://doi.org/10.1590/s0100-83582017350100067

FOOD AND AGRICULTURAL ORGANIZATION (FAO). *FAOSTAT data base for agriculture*. 2019. Available from: http://www.fao.org/statistics/en/. Access on: 3 Jun. 2019.

GALON, L. *et al*. Períodos de interferência de *Brachiaria plantaginea* na cultura do milho na região sul do Rio Grande do Sul. *Planta Daninha*, Viçosa, v.26, n.4, p.779-788, 2008. https://doi.org/10.1590/S0100-83582008000400009

GALON, L.; BAGNARA, M.A.M.; GABIATTI, R.L.; REICHERT JÚNIOR, F.W.; BASSO, F.J.M.; NONEMACHER, F.; AGAZZI, L.R.; RADUNZ, L.L.; FORTE, C.T. Interference periods of weeds infesting maize crop. *Journal of Agricultural Science*, Ontario, v.10, n.10, p.197-205, 2018b. https://doi.org/10.5539/jas.v10n10p197

GALON, L.; DAVID, F.A.; FORTE, C.T.; REICHERT JUNIOR, F.W.; RADUNZ, A.L.; KUJAWINSKI, R.; RADUNZ, L.L.; CASTOLDI, C.T.; PERIN, G.F.; MOSSI, A.J. Chemical management of weeds in corn hybrids. *Weed biology and management*, Utsunomiya, v.18, n.1, p.26-40, 2018a. https://doi.org/10.1111/wbm.12141

GALON, L.; TIRONI, S.P.; FERREIRA, E.A.; ASPIAZU, I.; PINTO, J.J.O. Avaliação do método químico de controle de papuã (*Brachiaria plantaginea*) sobre a produtividade do milho. *Pesquisa Agropecuária Tropical*, Goiânia, v.40, n.4, p.414-421, 2010. https://doi.org/10.1590/S1983-40632010000400019

GAZZIERO, D.L.P. Misturas de agrotóxicos em tanque nas propriedades agrícolas do Brasil. *Planta Daninha*, Viçosa, v.33, n.1, p.83-92, 2015. https://doi.org/10.1590/S0100-83582015000100010

GOULART, I.C.G.R.; NUNES, A.L.; KUPAS, V.; MEROTTO JUNIOR, A. Interações entre herbicidas e protetores para o controle de capim-annoni em pastagem natural. *Ciência Rural*, Santa Maria, v.42, n.10, p.1722-1730, 2012. https://doi.org/10.1590/S0103-84782012001000002

INTERNATIONAL HERBICIDE-RESISTANT WEED DATABASE (HEAP). *Herbicide Resistant Weeds in Brazil.* International survey of herbicide resistant weeds. 2019. Available from: http://www.weedscience.org/Summary/Country.aspx?CountryID=5. Access on: 19 Dec. 2019.

LUCIO, R.F.; KALSING, A.; ADEGAS, F.S.; ROSSI, C.V.S.; CORREIA, N.M.; GAZZIERO, D.L.P.; SILVA, A.F. Dispersal and frequency of glyphosate-resistant and glyphosate-tolerant weeds in soybean-producing edaphoclimatic microregions in Brazil. *Weed Technology*, Fayetteville, v.33, n.1, p.217-231, 2019. https://doi.org/10.1017/wet.2018.97

MELO, M.S.C.; ROSA, L.E.; BRUNHARO, C.A.C.G.; NICOLAI, M.; CHRISTOFFOLETI, P.J. Alternativas para o controle químico de capim-amargoso (*Digitaria insularis*) resistente ao glyphosate. *Revista Brasileira de Herbicidas*, Londrina, v.11, n.2, p.195-203, 2012. https://doi.org/10.7824/rbh.v11i2.145

MINISTÉRIO DA AGRICULTURA, PECUÁRIA E ABASTECIMENTO (MAPA/AGROFIT). *Sistemas de Agrotóxicos Fitossanitários* – Consulta Aberta. Available from: http://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons. Access on: 15 Dec. 2019.

OLIVEIRA, A.R.; FREITAS, S.P.; VIEIRA, H.D. Controle de *Commelina benghalensis*, *C. erecta*, *Tripogandra diuretica* na cultura do café. *Planta Daninha*, Viçosa, v.27, n.4, p.823-830, 2009. https://doi.org/10.1590/S0100-83582009000400021

SILVA, A.F.; ADEGAS, F.S.; CONCENÇO, G. Characterizations of Emergence Flows of Volunteer Corn as Function of Type of Harvest Grain Loss. *Journal of Agricultural Science*, Ontario, v.10, n.5, p.258-267, 2018. https://doi.org/10.5539/jas.v10n5p258

SOCIEDADE BRASILEIRA DE CIÊNCIA DO SOLO (NRS-SBCS); COMISSÃO DE QUÍMICA E FERTILIDADE DO SOLO (CQFS-RS/SC). *Manual de adubação e calagem para os estados do Rio Grande do Sul e Santa Catarina*. Porto Alegre: NRS-SBCS, 2016. 376p.

TIMOSSI, P.C.; FREITAS, T.T. Eficácia de nicosulfuron isolado e associado com atrazine no manejo de plantas daninhas em milho. *Revista Brasileira de Herbicidas*, Londrina, v.10, n.3, p.210-218, 2011. https://doi.org/10.7824/rbh.v10i3.123

VALDERRAMA, M.; BUZETTI, S.; BENETT, C.G.S.; ANDREOTTI, M.; TEIXEIRA FILHO, M.C.M. Fontes e doses de NPK em milho irrigado sob plantio direto. *Pesquisa Agropecuária Tropical*, Goiânia, v.41, n.2, p.254-263, 2011. https://doi.org/10.5216/pat.v41i2.8390

VARGAS, L.; AGOSTINETTO, D.; GAZZIERO, D.; KARAM, D. Resistência de plantas daninhas no Brasil: Histórico, custo, e o desafio do manejo no futuro. In: RÍOS, A. *Viabilidad del glifosato en sistemas productivos sustentables* (Serie Técnica 204). Montevideo: INIA, 2013. p.99-110. Available from: http://www.ainfo.inia.uy/digital/bitstream/item/7629/1/18429080413103109.pdf. Access on: 12 Dec. 2019

VELINI, E.D.; OSIPE, R.; GAZZIERO, D.L.P. *Procedimentos para instalação, avaliação e analise de experimentos com herbicidas*. Londrina: SBCPD, 1995. 42p.

WESTWOOD, J.H.; CHARUDATTAN, R.; DUKE, S.O.; FENNIMORE, S.A.; MARRONE, P.; SLAUGHTER, D.C.; SWANTON, C.; ZOLLINGER, R. Weed management in 2050: Perspectives on the future of weed science. *Weed science*, Georgia, v.66, n.3, p.275-285, 2018. https://doi.org/10.1017/wsc.2017.78