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Article

Interference Periods of Weeds in Maize in No-Tillage and Conventional Systems at High Altitudes

Períodos de Interferência de Plantas Daninhas na Cultura do Milho em Semeadura Direta e Convencional de Alta Altitude

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ABSTRACT - The objective of this study was to determine the coexistence periods of weeds (CTWR = critical timing of weed removal) and control (CWFP = critical weed-free period) in maize crops in no-tillage and conventional systems at high altitudes in southern Brazil. To this end, four experiments were conducted in Guarapuava-Paraná during the 2016/2017 crop season using P2530™ (conventional) and P3271H™ (transgenic genetically modified for glyphosate tolerance) hybrids in no-tillage and conventional systems with crop residues of black oat (*Avena strigosa*). The experimental design was a randomized complete block with five repetitions. The treatments were divided into periods of CTWR and CWFP for 0, 7, 14, 28, 42, 63, and 126 days after the emergence of crops (DAE). Among the weeds, only eudicotyledonous species predominated throughout the crop cycle in both production systems. The productivity results established for P2530™ and P3271H™ hybrids in a conventional system with the incorporation of straw in the soil indicated a critical period of weed control (CPWC) from 23 to 39 DAE and 23 to 35 DAE, respectively. For direct sowing (no-tillage system) on black oat straw, no CPWC was established, as it required only one single point of control between the periods of 21 to 33 DAE and 23 to 31 DAE for the P2530™ and P3271H™ hybrids, respectively. The direct sowing in black oat straw constituted an efficient strategy to reduce weed interference and the necessity of weed management practices.

Keywords: *Zea mays* L., competition, control, productivity.

*RESUMO - A presente pesquisa teve como objetivo determinar os períodos anterior à interferência (CTWR) e total de prevenção da interferência (CWFP) das plantas daninhas na cultura do milho, em sistemas de plantio direto e convencional em ambiente de elevada altitude, na região Sul do Brasil. Para isso, oito experimentos foram conduzidos em campo em Guarapuava-PR, durante a safra 2016/2017, utilizando os híbridos P2530® (convencional) e P3271H® (transgênico geneticamente modificado para tolerância ao glifosato) em sistema de semeadura direta e convencional com resíduos culturais de aveia-preta (**Avena strigosa**). O delineamento experimental foi o de blocos casualizados com cinco repetições. Os tratamentos foram divididos em períodos de CTWR e CWFP das plantas daninhas durante 0, 7, 14, 28, 42, 63 e 126 dias após a emergência da cultura (DAE). Entre as plantas daninhas, verificou-se predomínio apenas de espécies eudicotiledôneas durante todo o ciclo da cultura em ambos os sistemas de produção. Os resultados de produtividade permitiram estabelecer para os híbridos P2530® e P3271H®, cultivados em semeadura convencional com incorporação da palha ao solo, períodos críticos de prevenção à interferência (CPWC) entre 23 a 39 DAE e 23 a 35 DAE, respectivamente. Para a semeadura direta sobre a palha de aveia-preta,*

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não foram estabelecidos CPWC, sendo constatada a necessidade de apenas um único controle pontual entre os períodos de 21 a 33 DAE e 23 a 31 DAE para os híbridos P2530® e P3271H®, respectivamente. A semeadura direta em palha de aveia-preta constituiu-se estratégia eficiente para reduzir a matointerferência e a necessidade de práticas de manejo.

Palavras-chave: *Zea mays* L., competição, controle, produtividade.

INTRODUCTION

Brazil is one of the world's largest producers of maize, which is cultivated in all Brazilian states and has undergone a continuous increase in productive technology (Araujo et al., 2015). Despite its worldwide importance, this cereal still has a low yield due to various forms of stress to which it is subjected during its cycle. Among these stresses is competition with weeds.

Weeds and maize crops sharing the same space results in interspecific competition, which is characterized by a dispute between species, also known as weed competition (Dias et al., 2010). The competition between weeds and cultivated plants varies according to the diversity of species and agricultural practices adopted; the species that are most aggressive and most well-adapted to the ecosystem have greater advantages (Brighenti and Oliveira, 2001).

Maize crops can coexist with weeds for a certain period without any reduction in productivity. This period is called the critical time of weed removal (CTWR), in which the environment can provide the necessary growth resources for both the weed community and the culture (Velini, 1992). The period in which the crop can dominate the environment with the closure of the canopy, shading the rows and hindering the growth of weeds, is called the critical weed-free period (CWFP). According to Agostinetto et al. (2008), after that moment, the emerging weed will not further reduce the productivity of the crop, as it already has the capacity to suppress competing plants.

Thus, the time interval that defines the critical period of weed control (CPWC) is between the CTWR and CWFP, which is the period in which cultivated plants should not compete with weeds, in order to prevent yield losses (Rizzardi et al., 2014). According to Rizzardi et al., this period varies according to the maize crop and almost always occurs between stages V2 and V7 (two and seven developed leaves). Conversely, if the CTWR is longer than the CWFP, there is theoretically no CPWC. In this case, only control between the end of CWFP and CTWR could prevent the culture from being infested by weeds (Carvalho, 2013).

Knowing the critical periods of interference prevention enables the correct use of post-emergence herbicides, allowing the elimination of weeds at the ideal time. The application of pre-emergence herbicides can also control weeds until the CWFP period. Kozlowski (2002) highlights the importance of identifying this period for the management of weeds at the latest at the end of CTWR, since the crop and/or the weeds may reach a stage of development that makes control practices unfeasible.

One of the important alternative strategies for weed management and soil protection adopted in agricultural systems in southern Brazil is the practice of direct seeding (no-tillage system) with the maintenance of straw on the soil surface (Altieri et al., 2011). Black oats (*Avena strigosa*) are the most widely used mulch in production systems that precede maize cultivation in southern Brazil (Silva et al., 2006; Marchesan et al., 2016). In addition to the abundant root system and high production of dry matter for soil coverage, black oats also improve the physical, chemical, and biological properties of the soil, in addition to having slow decomposition (high C/N ratio) and high lignin content (Rizzardi and Silva, 2006).

The Guarapuava region, located in the center-south of the state of Paraná, stands out for its altitude, varying from 700 to 1,200 m above sea level. The region has a combination of soil and climatic conditions that are favorable to maize cultivation, such as sufficient rain distribution from September to March, mild night temperatures, thermal amplitude, and soil fertility favorable for high productivity. However, there are no studies reports on weed interference in maize crops in this region.

In this context, the aim of this study was to evaluate weed interference in maize crops in the Guarapuava/Paraná region during the 2016/2017 crop season by establishing the weeds coexistence period (CTWR - critical timing of weed removal) and control (CWFP - critical weed-free period) in two maize hybrids (P2530™ and P3271H™) cultivated in no-tillage and conventional systems.

MATERIALS AND METHODS

Eight experiments using P2530™ (conventional) and P3271H™ (genetically modified transgenic glyphosate tolerance) maize hybrids and no-tillage and conventional systems with black oat (*A. strigosa)* crop residues were conducted simultaneously in the experimental area of the farm-school of the Midwest State University - UNICENTRO, located in the municipality of Guarapuava-Paraná, at the geographical coordinates S 25°22'55.7", W 051°33'17.7" at 984 m during the 2016/2017 crop season.

The climate of the region is classified by Köeppen-Geiger as subtropical humid mesothermal Cfb (Peel et al., 2007), with cool summers, winters with occurrence of severe and frequent frosts, and no dry season. Average annual temperatures range from 16 °C to 17 °C, and average annual rainfall is around 1,500 mm. The daily meteorological data of temperature (maximum and minimum) and rainfall recorded during the conduction of the experiments are shown in Figure 1. They were obtained in the meteorological station of the Midwest State University.

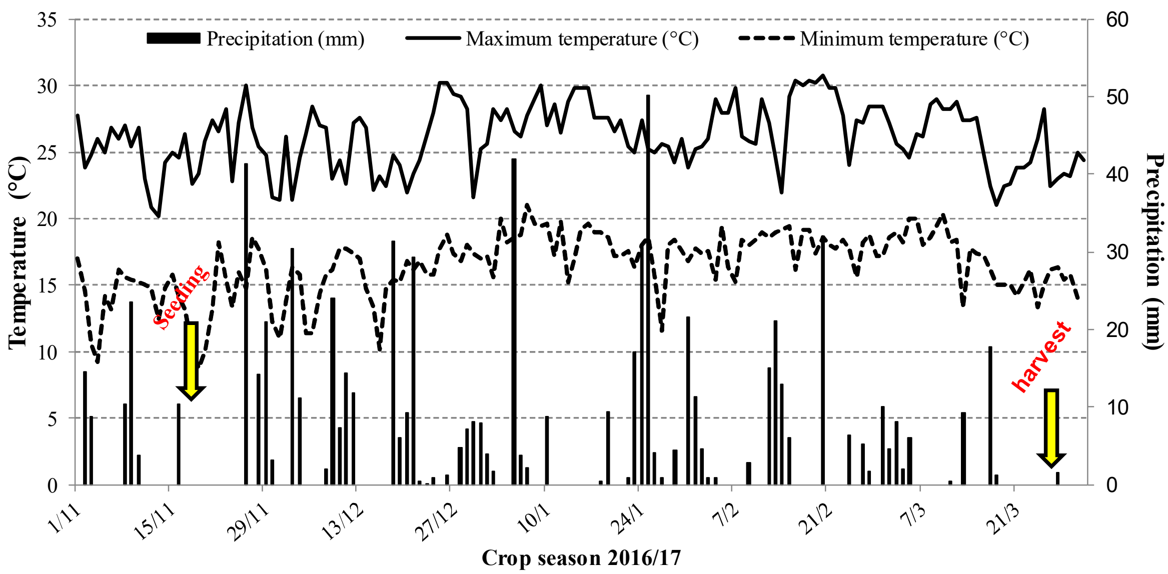

Figure 1 **-** Daily meteorological data of temperature (°C), relative air humidity (average %), and precipitation (mm) during field experiments of weed interference in maize crops in no-tillage and conventional systems. UNICENTRO - Guarapuava-Paraná, 2016/17 crop season.

The soil in the experimental area is classified as typical dystrophic Bruno Latosol with clayey texture (Embrapa, 2013), consisting of 560, 180, and 260 g kg^{-1} of clay, sand and silt, respectively. The soil had the following chemical characteristics while seeded during the experiment: pH ($CaCl_2$) of 4.77; H + Al^{+3} of 4.96 $cmol_c$ dm^{-3}; Ca^{+2} of 2.81 $cmol_c$ dm^{-3}; Mg^{+2} of 1.49 $cmol_c$ dm^{-3}; K+ of 0.31 $cmol_c$ dm^{-3}; P of 2.68 mg dm^{-3} (Mehlich); and C of 27 g dm^{-3}.

The experiments took place in an area initially containing black oats, cultivar IAPAR 61™, as mulch. Black oats were dissected in the reproductive stage, using 960 g ha^{-1} of glyphosate, with the subsequent grazing of the desiccated material to ensure better uniformity of the straw on the soil surface. Soon after this procedure, half of the experimental area was subjected to scarification and soil grading, with the incorporation of almost all the crop residue.

The levels of black oat straw on the soil surface in each production system (no-tillage and conventional) were estimated before seeding the crop. For this purpose, the black oat straw was collected and dried in an oven for five days at a temperature of 60 °C, resulting in 1.08 and 7.10 ton ha^{-1} of crop residues, respectively, for the no-tillage and conventional production systems.

Seeding was performed on November 16, 2016 using the hybrids P2530™ (conventional) and P3271H™ (genetically modified transgenic for glyphosate tolerance), with row spacing of 0.8 m, population of 62,500 plants ha^{-1} and base fertilization with 300 kg ha^{-1} of the formulation 8-20-20 (NPK). As a complement to mulch fertilization, 100 kg ha^{-1} of urea (45% N) was used in the V3-V4 stage of the crop. Mulch fertilization was applied superficially by hauling (without incorporation) and under good soil moisture conditions.

The experimental design was a randomized block design with five repetitions. The treatments were divided into periods of CTWR and CWFP during 0, 7, 14, 28, 42, 63, and 126 days after crop emergence (DAE). The experimental units consisted of plots with a total area of 3.5 x 4.0 m (14.0 m^2), containing four lines for the P2530™ and P3271H™ hybrids, both in no-tillage and conventional systems. The evaluations were performed in the central lines of the plots, which were defined as the useful area, disregarding 0.5 m at each end.

Fungicides and insecticides were applied in a preventive and curative manner, and, whenever necessary, control measures were adopted; the products and doses used were defined according to the technical recommendations for maize crops (Fávero et al., 2016).

At the end of each critical time of weed removal (CTWR), the experimental units were weaned weekly until harvest. In the treatments with the critical weed-free period (CWFP), the crop was weaned weekly only until the end of each predetermined period. At the end of each period of coexistence, weed density was determined and shoot dry mass (SDM) was quantified. This procedure was performed using a metallic jig (0.25 m^2) randomly launched in the experimental units. The shoot of the weeds was collected and separated by species and then dried in a forced air circulation oven at 60 °C until it reached a constant mass that was weighed with a precision scale.

At the end of the crop cycle, the height of the maize plants was determined using a graduated ruler. Six plants were randomly selected from each plot and measured from their base to the insertion of the flank. For standardization, the moisture of the grains was set to 13% and the mass was set to 100 grains (P100). The weight and productivity (kg ha^{-1}) of the hybrids were measured with a precision scale.

The results were submitted for analysis of variance using the F test ($p<0.01$ and 0.05) and regression analysis was performed using the SigmaPlot 11.0™ statistical software. The critical time of weed removal (CTWR) and critical weed-free period (CWFP) were determined estimating losses of 5% in relation to the weed-free treatment, considering that this value refers to the cost of chemical control. The critical period of weed control (CPWC) for each trial was determined as the interval between the CTWR and CWFP.

Regression studies were conducted to analyze the trends of the effects of the interference periods on grain productivity of the maize crop, and the Logistic sigmoidal and Gompertz adjusted mathematical models were used to estimate the CTWR (1) and CWFP (2), respectively, as described by Knezevic et al. (2002). These models best explained the biological behavior of the phenomenon under study, considering the significance of the parameters, the mean squares of the residues, and the values of R^2 (Alvarez and Alvarez, 2006).

$$Y = (Y0-A)/(1+ABS(DAE/K)*EXP(B)) \quad \text{(eq. 1)}$$

$$Y = (Y0-A)*EXP(-EXP(-(DAE-K)/B)) \quad \text{(eq. 2)}$$

where: Y refers to grain productivity, expressed in kg ha^{-1}; Yo refers to the smallest value of Y; A refers to the maximum asymptote, in kg ha^{-1}; DAE refers to the days after crop emergence when it remained weed-free or infested by weeds; and B and K are constants of the model.

RESULTS AND DISCUSSION

Both during the experiments in a no-tillage system with black oat straw on the soil and conventional tillage with development and incorporation of the straw into the soil, the maize crop was mainly infested by seven invasive eudicotyledonous weed species: arrowleaf sida (*Sida rhombifolia*), common sowthistle (*Sonchus oleraceus*), winged false buttonweed (*Spermacoce latifolia*), Mexican fireplant (*Euphorbia heterophylla*), morning glory (*Ipomoea grandifolia*), black-bindweed (*Polygonum convolvulus*), and common ragweed (*Ambrosia artemisiifolia*). The only weed variation observed in the production systems was the common sowthistle and Mexican fireplant weed species, which occurred exclusively in no-tillage and conventional systems, respectively.

The highest levels of weed growth were observed from the 7 DAE of the crop extending to 28 DAE in both production systems (Figure 2). It is noteworthy that despite the exclusive occurrence of eudicotyledonous weed species in both production systems, direct seeding in the straw significantly suppressed the emergence and development of weed emergence compared to conventional seeding. In general, the mean levels of reduction were 65.5% and 43.9% for the density and dry matter of weeds, respectively (Figure 2A, B).

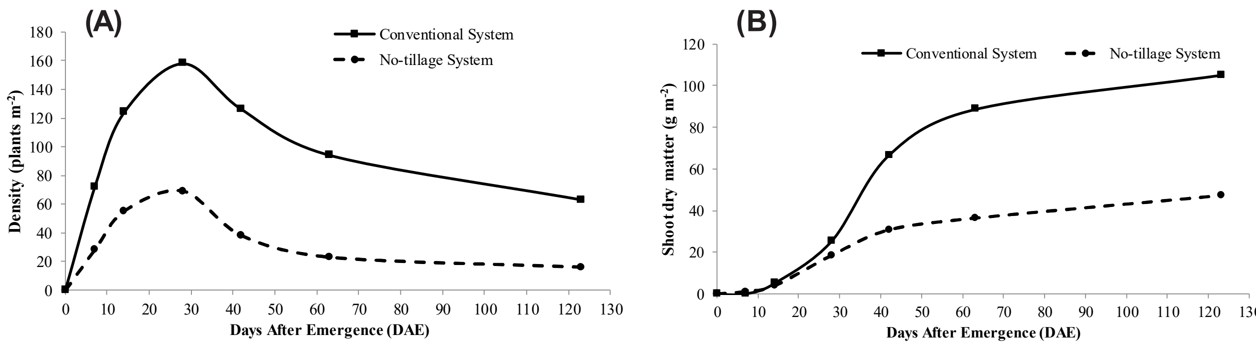

Figure 2 **-** Density (plants m^{-2}) (A) and shoot dry matter (g m^{-1}) (B) of the weeds after different periods of coexistence with the maize crop, hybrids P2530™ and P3271H™, in no-tillage system on straw (NTS) and conventional system (CS). Guarapuava-Paraná, 2016/17 crop season.

The reduction in density and increase in the weeds' dry biomass (Figure 2A, B) with the predominance of dominant species and crop development were also observed by Radosevich et al. (1997) and Rios (2012). According to Rios (2012), interspecific and intra-specific competition increases with the extension of the period, with more adapted individuals or those with greater cycles tending to dominate the space. Furthermore, the closure of the canopy of corn crop exerts cultural control, restricting the germination of new weeds by shading.

Weed dry matter accumulation remained at low levels for an initial period of approximately 14 DAE in the two production systems (Figure 2A). From the 28 DAE of the maize crop, there was a progressive and more intense increase of dry matter in the shoot of the weeds that lasted throughout the evaluation period (Figure 2B), always with greater formation of dry matter in the conventional system. In general, the weed community of the experiment was considered between low and moderate. However, sometimes, moderate weed infestations are as damaging to commercial crops as high infestations, depending on the prevailing species as well as their competitive abilities (Vasconcelos et al., 2012; Forte et al., 2017).

The height of the plants (Figure 3A, B) of the two maize hybrids (P2530™ and P3271H™) was influenced by the weeds, resulting in a reduction of the plant size according to the period of coexistence with weeds. The coexistence of maize hybrids with weeds in no-tillage and conventional systems resulted in lower crop growth soon after the first week (7 DAE), except for the hybrid P3271H™ in the conventional system, in which height started to reduce after the second week (14 DAE). According to Galon et al. (2008), height tends to be affected when the period of coexistence with weeds is long.

We observed that the two hybrids should remain free from weed infestation until approximately 42 DAE to avoid a reduction in plant height, regardless of the soil management system (Figure 3A, B). In general, maize hybrids had plants with higher final heights when they were subjected to direct seeding in the straw, regardless of the presence or absence of weeds. For the hybrid P3271H™, coexistence with weeds resulted in less difference in the height of the plants in the two management systems.

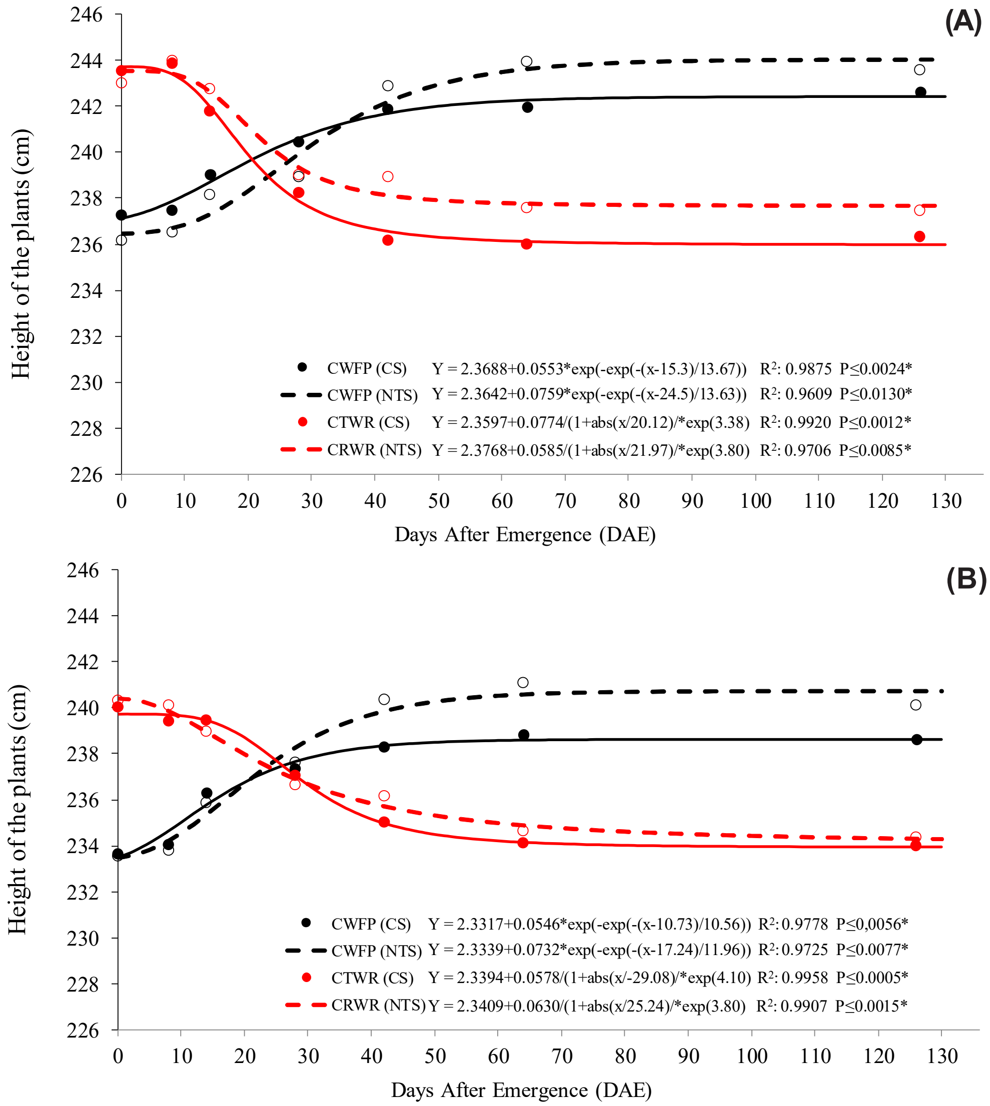

Figure 3 **-** Height of the plants of the maize hybrids P2530™ (A) and P3271H™ (B) after different periods of coexistence (CTWR) and control (CWFP) of weeds in no-tillage system on straw (NTS) and conventional system (CS). Guarapuava-Paraná, 2016/17 crop season.

Conversely, when assessing periods of moderate interference by the weed community on maize crops in two-row widths, Silva (2017) did not find significant variation in plant height between the periods of coexistence and infestation control. According to Duarte et al. (2002), plant height is an important characteristic that can be influenced by competition depending on the mode of weed growth and the period of competition. Rossi et al. (1996) found that weeds start interfering with the height of maize plants at 35 DAS (days after seeding). However, it is important to consider the great variety of existing hybrids and the different environmental conditions to which they are subjected, making it difficult for consistent results to occur (Rios, 2012).

No significant differences were found for the weight of 100 grains in the periods of coexistence and weed control to which the maize hybrids (P2530™ and P3271H™) were subjected, as well as between the soil management systems under study (Figure 4A, B). These results corroborate those reported by Campos et al. (2016), in which only the maize grown in the first crop season showed this behavior. Zagonel et al. (2000) observed that the delay in the weed control season did not affect the weight of 100 grains in the maize crop. Duarte et al. (2002) also reported that the weight of grains does not change when the weeds are eliminated by management practices until the tasseling of the maize crop.

The P3271H™ hybrid had a higher grain weight than the P2530™. In maize crops, grain weight is defined by the amount of carbohydrates accumulated during photosynthesis, and the

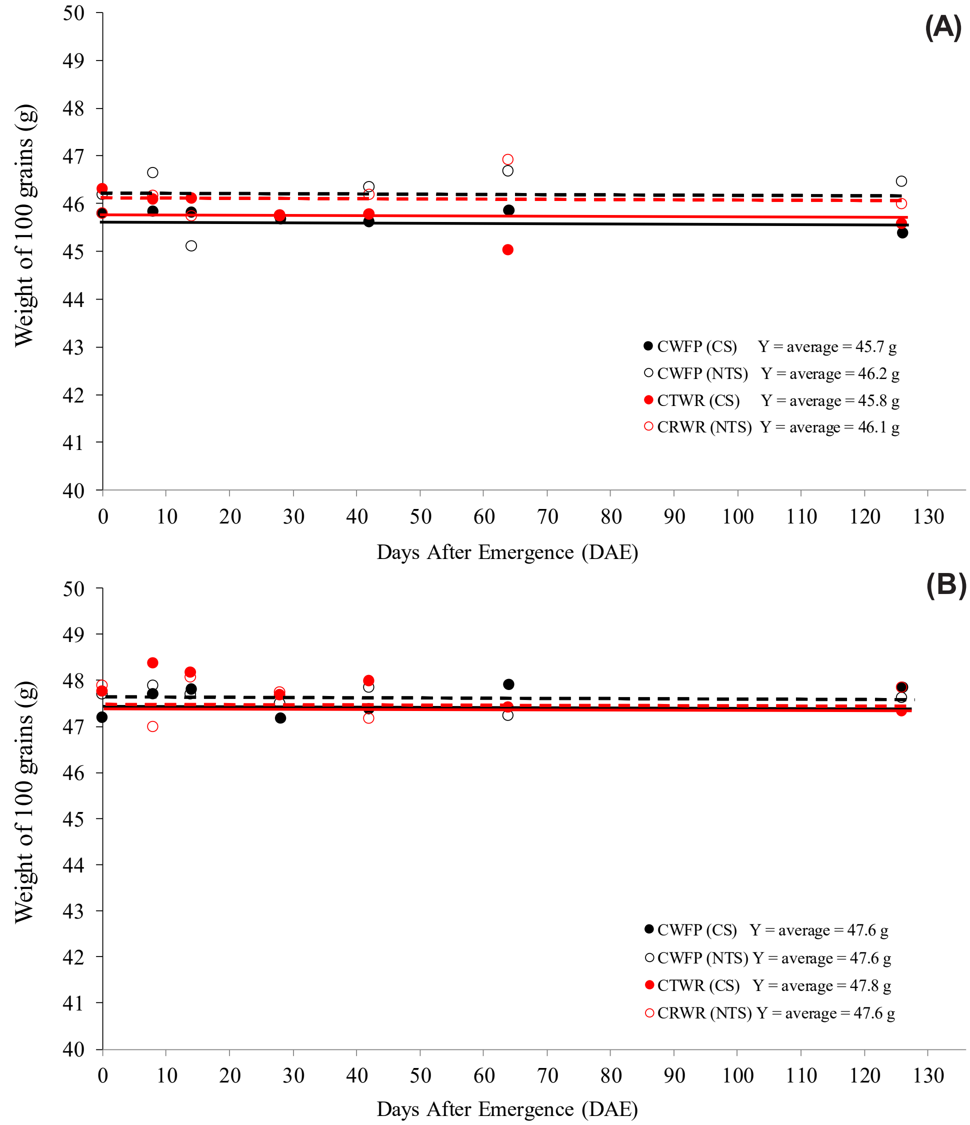

Figure 4 - Weight of 100 grains of the maize hybrids P2530™ (A) and P3271H™ (B) after different periods of coexistence (CTWR) and control (CWFP) of weeds in no-tillage system on straw (NTS) and conventional system (CS). Guarapuava-Paraná, 2016/17 crop season.

period of grain filling is that between the emission of stigmata and physiological maturation (Daynard and Kannenberg, 1976).

Grain productivity results indicated that in the conventional system (CS), the maize hybrids P2530™ and P3271H™ coexisted (CTWR) with weeds without yield losses up to 23 DAE (Figure 5A, B). However, in order to prevent coexistence (CWFP) with weeds, it is necessary for the crop to remain clean with control practices up to 39 and 35 DAE for the hybrids P2530™ and P3271H™, respectively.

Therefore, the critical period of weed control (CPWC) for conventional seeding was between 23 to 39 AEDs and 23 to 35 AEDs for the hybrids P2530™ and P3271H™, respectively. In practice, the determination of CPWC for maize hybrids in the Guarapuava-Paraná region works as a preventive strategy for farmers by precisely establishing the time during which the crop must remain free from weeds. Thus, the farmer can more assertively apply selective herbicides in the post-emergence period of the maize crop before the beginning of CTWR, establishing new control measures if new weeds emerge by the end of the CWFP. Another option is to use herbicides with a residual effect on the soil that can control the seed bank of weeds contained in the area until the end of the CWFP determined for each hybrid.

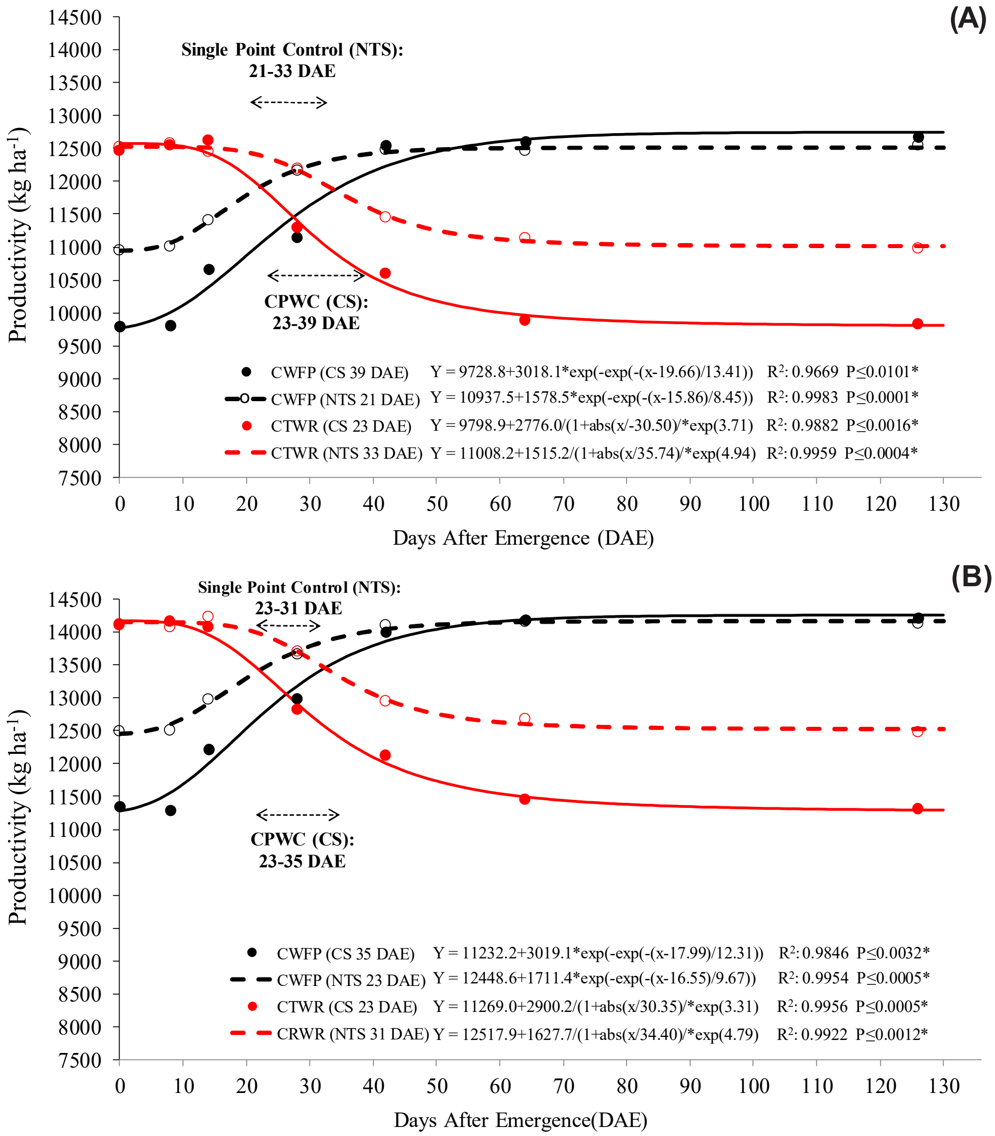

Figure 5 **-** Productivity of maize crops, hybrids P2530™ (A) and P3271H™ (B) after different periods of coexistence (CTWR) and control (CWFP) of weeds in no-tillage system on straw (NTS) and conventional system (CS). Guarapuava-Paraná, 2016/17 crop season.

Weed coexistence during the entire crop cycle resulted in productivity losses of around 21.9% and 20.3% for the hybrids P2530™ and P3271H™, respectively, in conventional systems.

In the no-tillage system, a CTWR of 33 and 31 DAE and a CWFP of 21 and 23 DAE were determined for the maize hybrids P2530™ and P3271H™, respectively. The yield reduction in the absence of weeds in the area during the entire cycle in relation to the period of coexistence with weeds was 12.7% and 11.5% for the hybrids P2530™ and P3271H™, respectively. As in this case, the CTWR values were higher than the CWFP values, and the only management strategy adopted is single point control, which should be performed only once between 21 to 33 DAE and 23 to 31 DAE for the hybrids P2530™ and P3271H™, respectively, without the need to monitor new emerging plants. In this context, single point control exclusively with herbicides applied in post-emergence and without residual action, such as glyphosate and glufosinate ammonium (Herculex™ in maize and Liberty Link™ in cotton), is sufficient to prevent any loss of productivity in crops with CTWR > CWFP behavior, as long as the weed community does not show resistance to these active ingredients.

Some studies on weed interference conducted in maize crops near the Guarapuava/Paraná region, such as that of Zagonel et al. (2000) in Ponta Grossa/Paraná, observed that a delay in the period of weed control from 10 DAE negatively affected the productivity and components of production. Kozlowski et al. (2009) determined the CTWR for maize grown in the municipality of Fazenda Rio Grande/Paraná as 9 DAE. Rios (2012), studying weed interference in maize crops in the city of Maringá/Paraná, established a CTWR of 18 and 14 DAE for a row spacing of 0.9 and 0.45 m and a CTWR of 26 and 5 DAE for "high" and "low" populations, respectively.

Therefore, the degree of weed interference can be influenced by several factors, such as the hybrid, soil management and mulch, the altitude of the site, and the crop to be planted among other factors. Thus, the results obtained may vary significantly and regional studies should be conducted in order to establish a better direction for a given condition, facilitating the adoption of more proactive control measures.

The productivity results allowed to establish critical periods of weed control (CPWC) between 23 to 39 DAE and 23 to 35 DAE for the hybrids P2530™ and P3271H™, cultivated in conventional systems with the incorporation of straw in the soil, respectively. No CPWCs were established for the direct seeding on black oat straw, and only a single point control was necessary between the periods of 21 to 33 DAE and 23 to 31 DAE for the hybrids P2530™ and P3271H™, respectively. Moreover, it is noteworthy that direct seeding on black oat straw was an efficient strategy to reduce weed interference and the need for management practices in maize crops.

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