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Periods of weed interference in garlic crop

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ABSTRACT. Garlic cultivation holds significant importance in Brazil. However, research on garlic crops is currently limited and outdated, highlighting the necessity for new studies, particularly focused on enhancing weed management and optimizing the use of agricultural inputs. This study aimed to assess the extent of yield losses attributed to weed interference and the specific periods during which weed interference impacts garlic crop yields in the state of Santa Catarina, Brazil. The experiments were conducted in Curitibanos, Santa Catarina State, Brazil, during 2019 and 2020, using the garlic cultivars Chonan and Ito, respectively. A randomized block experimental design was employed, consisting of 16 treatment groups with four replications. The design incorporated a 2×8 factorial arrangement, involving two weed management strategies (coexistence and control) and eight crop-weed coexistence periods (0, 15, 30, 45, 60, 90, 120, and 130 days after crop emergence – DAE). The study evaluated the weed community and recorded data on the number of bulbs, bulb diameter, as well as total and commercial bulb yields of garlic crops. The results indicated average losses of 24.3% in total bulb yield and 28.9% in commercial bulb yield. Critical periods for effective weed control were identified as 6 to 126 DAE in 2019, 5 to 126 DAE in 2020 for total yield, 3 to 126 DAE in 2019, and 5 to 126 DAE in 2020 for commercial bulb yield. Consequently, it is imperative to maintain garlic crops weed-free throughout most of their growth cycle.

Keywords: *Allium sativum*; alliaceae; competition; yield.

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Introduction

Garlic (*Allium sativum* L.) is an herbaceous vegetable species belonging to the Alliaceae family. It features elongated, narrow, waxy leaves and a fasciculate root system, with its height reaching up to 60 cm depending on the cultivar (Resende, Haber, & Pine, 2015; Brewster & Rabinowitch, 2020). Garlic crops have a lengthy growth cycle and slow shoot development, resulting in limited soil coverage and canopy closure. Their shallow, fasciculate root systems exploit a relatively small soil volume (Sahoo, Patel, Baldaniya, Chavan, & Murmu, 2018; Brewster & Rabinowitch, 2020). This combination of factors creates favorable conditions for weed germination, emergence, and growth (Guerra et al., 2020; Paula et al., 2022).

Furthermore, garlic crops demand frequent irrigation and substantial nutrient input, necessitating large amounts of fertilizers. This creates an environment conducive to weed growth, as weeds tend to be more efficient in using environmental resources (Brewster & Rabinowitch, 2020; Jiku et al., 2020; Oliveira et al., 2021; Hahn et al., 2022; Guerra et al., 2020).

Beyond competing for essential resources required for plant growth, weeds can also serve as hosts for pests and diseases that affect crops. Marcuzzo and Santos (2021) reported that weed species like *Galinsoga parviflora* and *Amaranthus viridis* can host the bacterium *Pseudomonas marginalis* pv. *marginalis*, the causal agent of leaf blight in garlic crops, for up to five months after garlic harvesting. Consequently, these weeds act as sources of inoculum for the disease in the subsequent garlic crop season.

Determining the optimal period for controlling weeds in garlic crops is crucial for achieving high yields and producing high-quality, valuable bulbs. Therefore, tests are conducted to establish the period before weed interference (PPI) and the total period for interference prevention (TPIP). PPI refers to the time from planting or emergence during which the crop can coexist with the weed community without negatively affecting acceptable crop yield levels. During this period, the growing environment can adequately supply the nutritional, hydrological, and light requirements of both the crop and the weed community. TPIP, on the other hand, is the period from planting or emergence during which the crop must be kept free of weeds to prevent negative impacts on bulb yield. Weed species infesting the area after this period will not significantly harm the crop. If TPIP exceeds PPI, a third period known as the critical period of weed control (CPWC) emerges. This interval represents the period in which weed control measures are necessary to prevent substantial negative effects on yields (Silva, Aguiar, Mendes, & Silva, 2022). The CPWC's duration depends on factors related to the cultivar, weed species, and environmental conditions (Silva et al., 2022).

Garlic crops hold substantial socioeconomic significance in Santa Catarina State, which ranks as the third-largest garlic-producing state in Brazil, following Minas Gerais and Goiás. In the 2022/2023 crop season, garlic cultivation in Santa Catarina spanned 1,490 hectares, yielding 16,201.0 Mg, and averaging 10,863 kg ha^{-1}. Most of this production stems from family farming (Empresa de Pesquisa Agropecuária do Estado de Santa Catarina [EPAGRI], 2023). Despite their importance, garlic crops in Santa Catarina occupy a relatively small area compared to other crops, and research on this crop remains limited and outdated. Previous studies primarily focused on genetic materials, fertilizer applications, and pest and disease management practices no longer applicable to modern garlic farming. Consequently, research aimed at enhancing weed management practices for current garlic crops is imperative to support growers in preventing losses in bulb yield and quality.

Hence, the objective of this study was to determine yield losses attributable to weed effects and identify the periods of weed interference in garlic crops in the state of Santa Catarina, Brazil.

Material and methods

Two experiments were conducted during the 2019 and 2020 crop seasons in commercial areas owned by the company *Rika Agropecuária*, located in Curitibanos, Santa Catarina State, Brazil. These experimental areas were situated at altitudes of approximately 1,000 meters and positioned at 27°22'04.7" S and 50°34'52.4" W in 2019 and 27°14'11.4" S and 50°37'04.2'' W in 2020. Both areas featured a soil classified as Typic Dystrudept (Cambissolo Háplico in Brazilian Classification; Santos et al., 2018), characterized by good drainage and a slightly hilly topography. Table 1 provides the physical-chemical properties of the soil in the study areas.

Table 1. Physical-chemical properties of the soil from the experimental areas in Curitibanos, Santa Catarina State, Brazil (2019 and 2020 crop seasons).

			2019			
pH	Al^{3+}	$H^+ + Al^{3+}$	$Ca^{2+} + Mg^{2+}$	Ca^{2+}	K^+	
$CaCl_2$			$cmol_c\ dm^{-3}$			
5,10	0,0	0,0	11,06	8,35	0,42	
P	O.M.	CEC	SB	Clay	Silt	Sand
mg dm^{-3}	g dm^{-3}	$cmol_c\ dm^{-3}$	%		g kg^{-1}	
30.08	39.78	17.79	65.09	637	175	187
			2020			
pH	Al^{3+}	$H^+ + Al^{3+}$	$Ca^{2+} + Mg^{2+}$	Ca^{2+}	K^+	
$CaCl_2$			$cmol_c\ dm^{-3}$			
6.10	0.0	0.0	16.06	12.35	0.76	
P	O.M.	CEC	SB	Clay	Silt	Sand
mg dm^{-3}	g dm^{-3}	$cmol_c\ dm^{-3}$	%		g kg^{-1}	
29.13	35.65	19.87	75.56	725	158	117

P: phosphorus content; O.M.: organic matter content; CEC: cation exchange capacity; SB: sum of bases.

The region experiences an average annual temperature ranging from 16 to 17°C and annual rainfall depths between 1,500 and 1,700 mm. The climate is classified as Cfb, characterized as temperate, humid mesothermal with a mild summer (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2013). Figure 1A and B depict rainfall depths and maximum and minimum temperatures recorded in Curitibanos during the experimental periods in 2019 and 2020, respectively.

The soil in the experimental areas was prepared using conventional tillage, involving plowing and harrowing, followed by two passes with a rotary tiller. The first pass occurred after harrowing, and the second took place on the day of garlic planting. Each experimental unit consisted of three double planting rows, with a spacing of 0.10 meters between rows and 0.35 meters between double rows, resulting in a planting density of 10 cloves per meter. The plot dimensions were 2.0 meters in length and 1.2 meters in width, conforming to the standard bed width of 0.15 meters and totaling 2.4 m^2 per plot. The evaluation area encompassed the two central planting rows, excluding the two side double rows and 0.5 meters at both ends of each row.

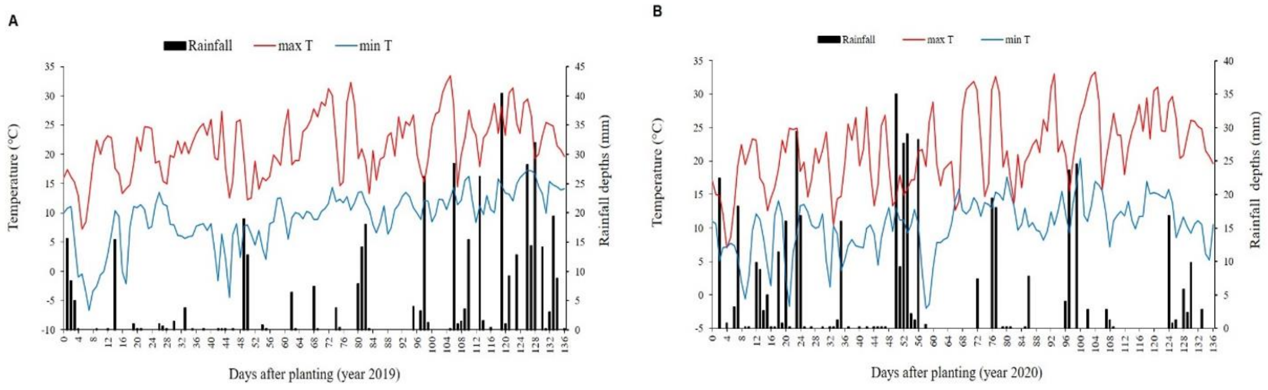

Figure 1. Minimum and maximum temperatures (ºC) and rainfall depths (mm) during the experimental periods of 2019 (A) and 2020 (B), in Curitibanos, Santa Catarina State, Brazil.

Garlic cloves from the Chonan cultivar (2019) and the Ito cultivar (2020) underwent vernalization in a cold chamber, maintained at temperatures of 3 to 5°C and relative humidity levels of 65% to 70%, for 25 days before planting. The Chonan cultivar, planted on July 1, 2019, belongs to the Nobre class and exhibits a late growth cycle of up to 150 days (). Similarly, the Ito cultivar, planted on June 24, 2020, also belongs to the Nobre class and features a late cycle of up to 150 days. It is among the most widely grown cultivars in Brazilian garlic-producing regions (Resende, Haber, & Pine, 2015)

Soil fertilization was performed at planting time in both crop seasons. It involved applying 1,000 kg ha^{-1} of the 04-14-08 N-P-K fertilizer formulation and 4,000 kg ha^{-1} of poultry litter before bed formation. Nitrogen fertilizer was applied throughout the garlic cycle, divided into three applications, using urea (45% N) as the nitrogen source. Cultural practices, including irrigation and pest and disease management, were carried out as required, adhering to crop-specific recommendations.

A randomized block experimental design was employed, featuring 16 treatments and four replications, with each block corresponding to one bed. The treatments were organized in a 2 × 8 factorial arrangement, involving two weed management strategies (coexistence and control) and eight crop-weed coexistence periods: 0, 15, 30, 45, 60, 90, 120, and 130 days after crop emergence (DAE). Weed control was executed by manually removing weeds between rows and in proximity to garlic plants during each coexistence or control period.

Weeds within the plots were collected at intervals of 15, 30, 45, 60, 90, and 120 days after emergence (DAE) of garlic plants, as well as just before harvest (130 DAE). This collection aimed to identify the weed species affecting the crop, assess weed density, and determine the dry matter weight of weeds accumulated throughout the garlic crop cycle. Weed samples were gathered from 0.25 m² areas, counted, identified, and subsequently dried in a forced air circulation oven at 55°C for 5 days. Following drying, the weed samples were weighed using an analytical balance to establish their dry weight.

Garlic plants within the evaluation area (0.45 m²) of each plot were manually harvested at the end of the crop cycle, occurring on November 13, 2019, and November 10, 2020, respectively. Subsequently, these garlic plants underwent curing, a dehydration process, on benches within a greenhouse. The number of garlic plants per meter (stand) was determined by counting plants in one meter of two central rows within each plot before harvesting. Bulb diameter measurements were conducted after the curing process, employing a digital caliper, while the total and commercial bulb weights were determined using a precision balance. Results for bulb weight were extrapolated to ascertain total yield and commercial bulb yield. Classification of garlic bulbs followed the guidelines outlined in Ordinance No. 241 of the Brazilian Ministry of Agriculture, Livestock, and Supply (MAPA, 1999), where bulbs with cross-sectional diameters greater than 32 mm and displaying acceptable appearance were categorized as commercial bulbs.

The data were subjected to analysis of variance using the F test and regression analysis at a significance level of 5% ($p < 0.05$). Periods of prior weed interference (PPI) and total periods of interference prevention (TPIP) were determined based on the results of garlic total and commercial bulb yields obtained from the regression analysis, considering yield losses of 1% as acceptable. This 1% threshold was chosen as acceptable due to the high market value of garlic. Accepting greater losses would result in reduced profitability for producers. All statistical analyses were conducted using SISVAR and SigmaPlot software.

Results and discussion

In the 2019 crop season, the experimental area was predominantly infested with weed species such as *Poa annua*, *Lolium multiflorum*, *Soliva pterosperma*, *Sisyrinchium* sp., *Senecio brasiliensis*, *Euphorbia heterophylla*, and *Ipomoea* spp. These weeds were present throughout the crop development cycle, with varying densities depending on the season (winter or spring). In the 2020 crop season, weed infestation consisted of *Cyclospermum leptophyllum*, *S. pterosperma*, *Coronopus didymus*, *Sida rhombifolia*, *Trifolium repens*, and *Solanum sisymbriifolium*. Many of these species were previously identified by Lucini (2010) as primary weeds in garlic crops in Santa Catarina State, Brazil.

In 2019, the number of weeds infesting garlic crops remained stable from 86 days after emergence (DAE) onward, with 18 plants per 0.25 m² (Figure 2A). Weed dry matter accumulation was slow until 60 DAE but increased significantly thereafter until the end of the crop cycle (130 DAE), reaching 117.52 g per 0.25 m² (Figure 2B). This increase in weed dry matter after 60 DAE was directly related to rising temperatures (Figure 1A) in mid-September in the Curitibanos region, promoting rapid germination, emergence, and development of summer annual weeds.

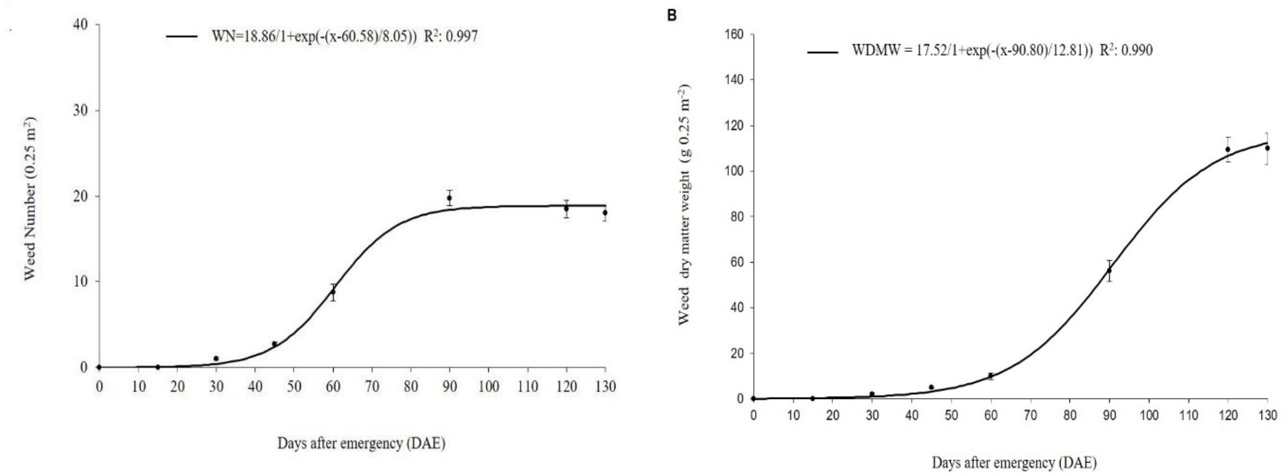

Figure 2. Number (A) and dry matter weight (B) of weeds over the garlic crop growth cycle for the cultivar Chonan. Curitibanos, Santa Catarina State, Brazil, 2019.

The dry matter weight of weeds infesting garlic crops in 2020 was higher than that in 2019. A low infestation was observed in the first 30 DAE, but it stabilized at 54 DAE, with 28 plants per 0.25 m² (Figure 3A). The accumulation of dry matter was slow until 45 DAE but increased significantly throughout the evaluation period, reaching 154.38 g per 0.25 m² by the end of the crop cycle (Figure 3B).

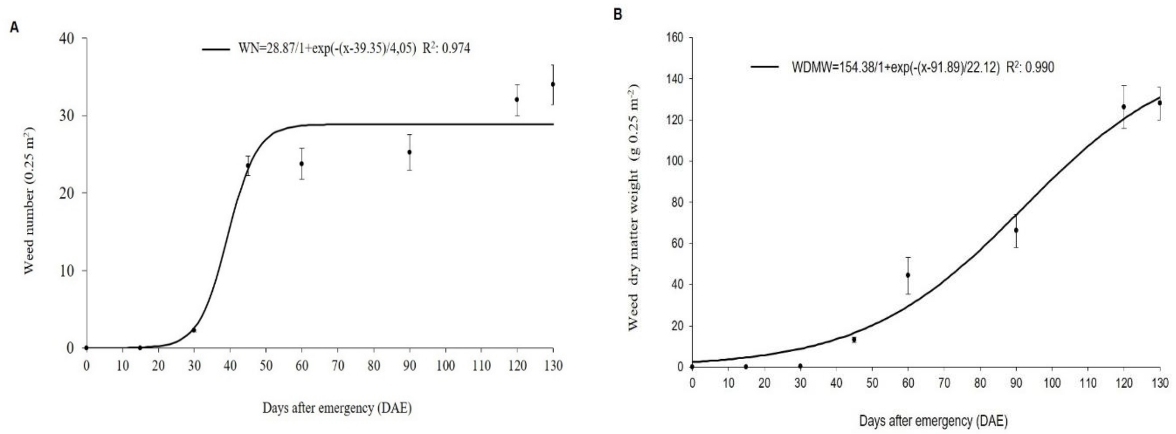

Figure 3. Number (A) and dry matter accumulation (B) of weeds throughout the garlic growth cycle for the cultivar Ito in Curitibanos, Santa Catarina State, Brazil, 2020.

Analysis of variance indicated that the number of garlic bulbs per meter (stand) was not affected by weed management (coexistence and control) during any of the evaluated periods and crop seasons (data not shown). In 2019, the effect of the interaction between factors or the effect of isolated factors was not significant for bulb diameter (data not shown). However, in 2020, the interaction effect was significant.

In 2020, when garlic bulbs had diameters greater than or equal to 45 mm, they were classified as commercial. However, as the crop-weed coexistence period increased, bulb diameters decreased. Bulbs that initially measured approximately 52 mm (class 6 bulbs), when there was no coexistence with weeds, it reduced to 45 mm (class 5 bulbs) when coexisting with weeds throughout the entire cycle. Conversely, increasing control periods led to bulbs initially measuring 50.5 mm (class 6 bulbs) when weed control was maintained throughout the crop cycle, but this decreased to 44.5 mm (class 5 bulbs) when no weed control was implemented (Figure 4). The significant effect on mean bulb diameter was observed only in the 2020 experiment, possibly due to higher weed infestation that year (Figure 3A).

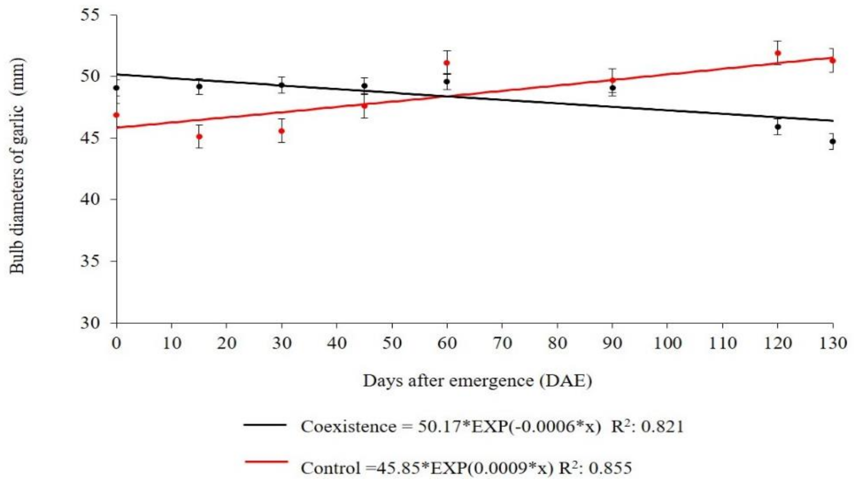

Figure 4. Bulb diameters of garlic crops of the cultivar Ito after different periods of coexistence with weeds and weed control. Curitibanos, Santa Catarina State, Brazil, 2020.

Yields of total and commercial bulbs (diameters ⩾ 32 mm) in both 2019 and 2020 were significantly affected by the factors studied, with notable impacts arising from the interaction between weed management (coexistence and control) and crop-weed coexistence or control periods.

In the case of the Chonan garlic cultivar in 2019, when no weeds were present, bulb yield reached 15,450 kg ha^{-1}, while coexistence with weeds throughout the crop cycle resulted in a yield of 11,680 kg ha^{-1}, reflecting a reduction of 3,770 kg ha^{-1}, or approximately 24.3% (Figure 5).

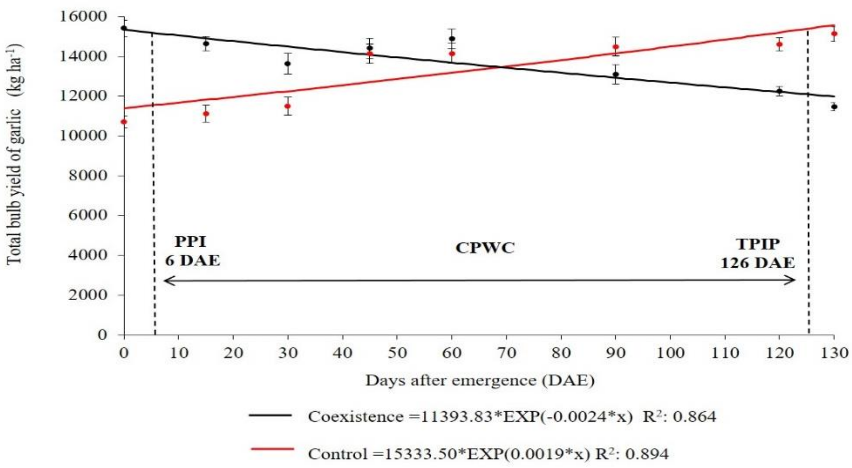

Figure 5. Total bulb yield of garlic crops of the cultivar Chonan after different periods of coexistence with weeds (PPI) and weed control (TPIP). Curitibanos, Santa Catarina State, Brazil, 2019.

For the Ito cultivar in 2020, the total bulb yield was 18,009 kg ha^{-1} in the absence of weeds. However, with weed presence throughout the entire cycle, the yield dropped to 12,398 kg ha^{-1}, representing a decrease of 5,611 kg ha^{-1}, or 28.9% (Figure 6).

Rahman et al. (2011) observed higher garlic bulb yield (15,000 kg ha^{-1}) with manual weeding at 15-day intervals, which was 50% higher than that of the control without weeding throughout the crop cycle and 20% higher than weeding at 30-day intervals. Zahadipour, Joghan, and Zare (2022) reported yield decreases of 100% when weed management commenced 120 days after crop emergence and decreases of 86% when control was carried out only in the first 20 days after crop emergence (Figure 6).

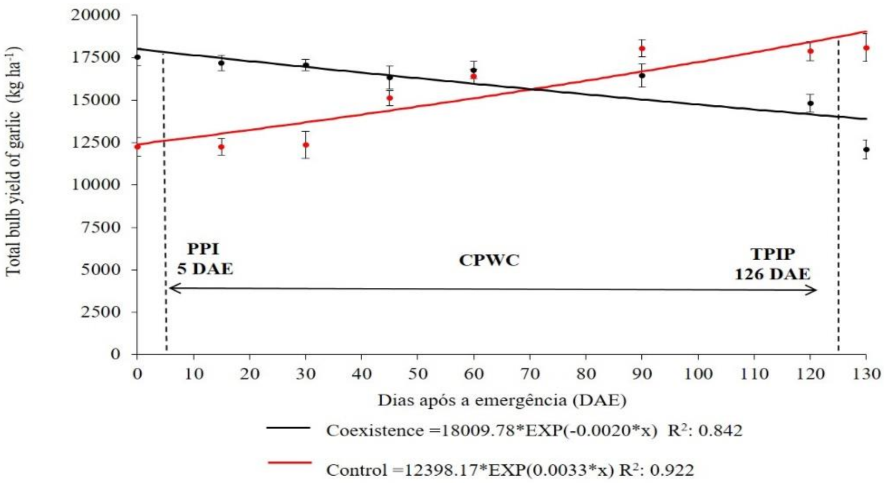

Figure 6. Total bulb yield of garlic crops of the cultivar Ito after different periods of coexistence with weeds (PPI) and weed control (TPIP). Curitibanos, Santa Catarina State, Brazil, 2020.

Accepting a 1% loss in total bulb yield as tolerable and considering the high market value of garlic, the period before weed interference (PPI) in the experiments was determined to be 6 days for the 2019 crop season and 5 days for the 2020 crop season (Figures 5 and 6). This indicates that during the first 6 or 5 days after crop emergence, the coexistence of garlic crops with weeds led to reductions of up to 1% in bulb yield. The total period of interference prevention (TPIP) was 126 days for both crop seasons, meaning that beyond this period, weed control did not result in significant yield increases (higher than 1%). As TPIP was longer than PPI, a critical period of weed control (CPWC) was established, commencing at 6 DAE in 2019 and 5 DAE in 2020, lasting until 126 DAE. Weed control during this approximately 120-day period was essential to prevent losses greater than 1% in total bulb yield (Figures 5 and 6). The extended weed control period was due to the small canopy and slow canopy closure of garlic crops (Brewster & Rabinowitch, 2020).

Commercial garlic bulb yield, which considers bulb appearance and diameter, was also evaluated concerning the effects of crop-weed coexistence or weed control. Commercial bulbs were defined as those with diameters exceeding 32 mm and suitable appearance for marketing, meaning they featured intact tunics without visible or damaged cloves (MAPA, 1999). According to Sahoo et al. (2018), reductions in garlic bulb yield are linked to decreases in bulb diameter, thereby impacting market value.

In 2019, weed control was implemented from 3 DAE to 126 DAE to prevent reductions greater than 1% in commercial bulb production. The critical period of weed control spanned 123 days (Figure 7), which was 3 days longer than that for total bulb yield. Consequently, maintaining the crop free of weeds until harvest was required for commercial bulb production. This occurred because bulbs require more reserves and hence become more prone to competition with weeds for resources. A loss of 4,076 kg ha^{-1} was observed in 2019 when comparing treatments with crop-weed coexistence throughout the entire cycle to those with continuous weed control, representing a reduction of approximately 31%, which was 6.7% higher than the reduction observed in total yield.

Regarding commercial garlic bulb yield in the 2020 crop season, weed control was necessary from 5 DAE to 126 DAE, resulting in a critical weed control period of 120 days (Figure 8). This was the same period identified for total yield. Losses in commercial garlic bulb yield for treatments with continuous crop-weed coexistence throughout the cycle were 5,343 kg ha^{-1}, corresponding to approximately 27.4%, and 1.5% higher than the losses observed in total yield.

Despite differences in weed species, weed density, dry matter weight, garlic cultivars, and climatic conditions between the 2019 and 2020 experiments, the identified PPI, TPIP, and yield reduction percentages were consistent. However, other studies on the impact of weeds on garlic bulb yield have reported greater losses. Qasem (1996), for instance, Kumar, Rana, Chandler, and Sharma (2013), and Sahoo et al. (2018) found yield reductions of 85.0, 72.5, and 94.8%, respectively; however, these studies were conducted in different countries, with varying edaphoclimatic conditions and weed species compared to those in Curitibanos, Santa Catarina State, Brazil. These variations are typical since weed effects depend on numerous factors, including the weed species infesting the area, weed density, garlic cultivar, edaphoclimatic conditions, and crop management. Weeds can negatively impact garlic bulb yield by competing for nutrients, water, and light, serving as hosts for pests and diseases (Marcuzzo & Santos, 2021), and releasing allelochemicals that inhibit crop growth.

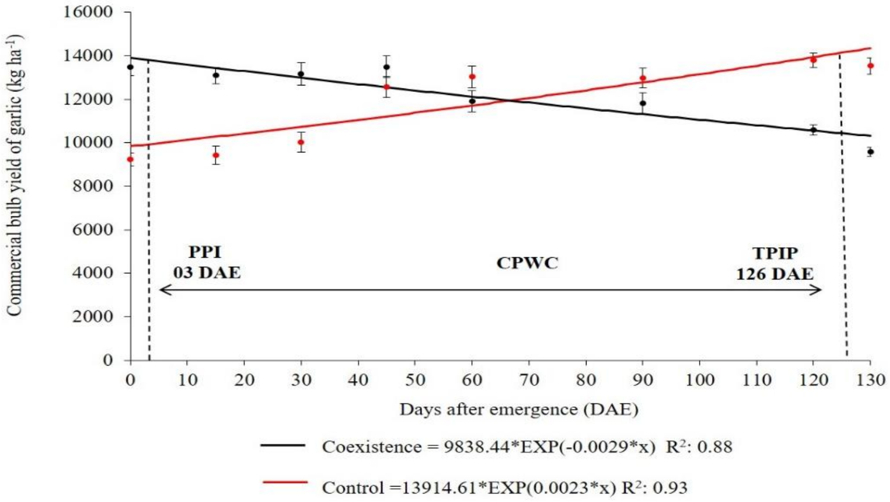

Figure 7. Commercial bulb yield of garlic crops of the cultivar Chonan after different periods of coexistence with weeds (PPI) and weed control (TPIP). Curitibanos, Santa Catarina State, Brazil, 2019.

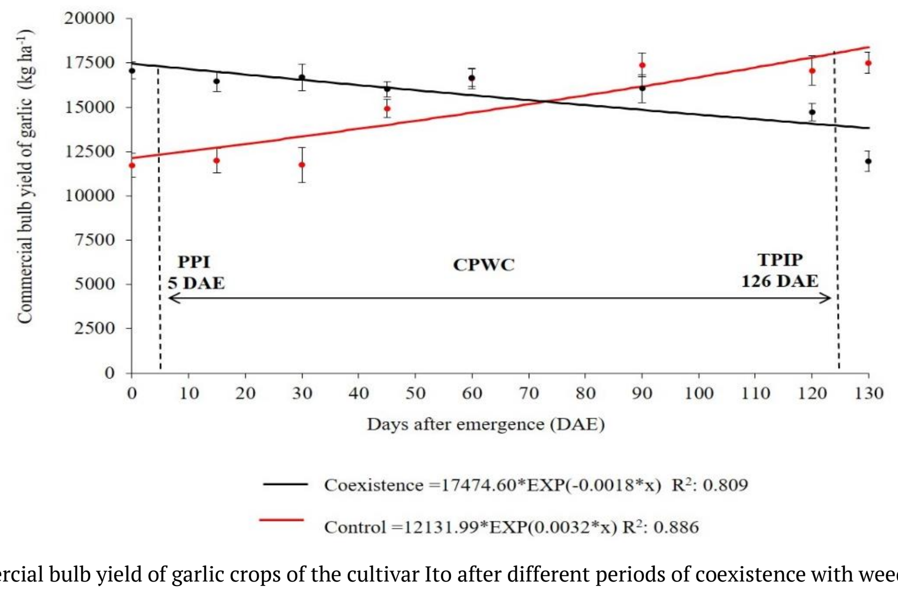

Figure 8. Commercial bulb yield of garlic crops of the cultivar Ito after different periods of coexistence with weeds (PPI) and weed control (TPIP). Curitibanos, Santa Catarina State, Brazil, 2020.

The periods of interference defined emphasize the need for weed control throughout most of the garlic crop cycle (Figure 9). According to Guerra et al. (2020), weed control until harvest is essential to prevent bulb damage during uprooting. Weeds not only directly affect yield but also, if present at harvest, can impact bulb quality by increasing tunic damage. This is because even if a bulb has a suitable diameter for commercial classification, it cannot be considered a commercial bulb if its appearance is compromised. As Lucini (2010) pointed out, the presence of weeds at harvest complicates bulb peeling and raises bulb losses during uprooting, requiring more labor for harvesting and often necessitating weed-free conditions until harvest.

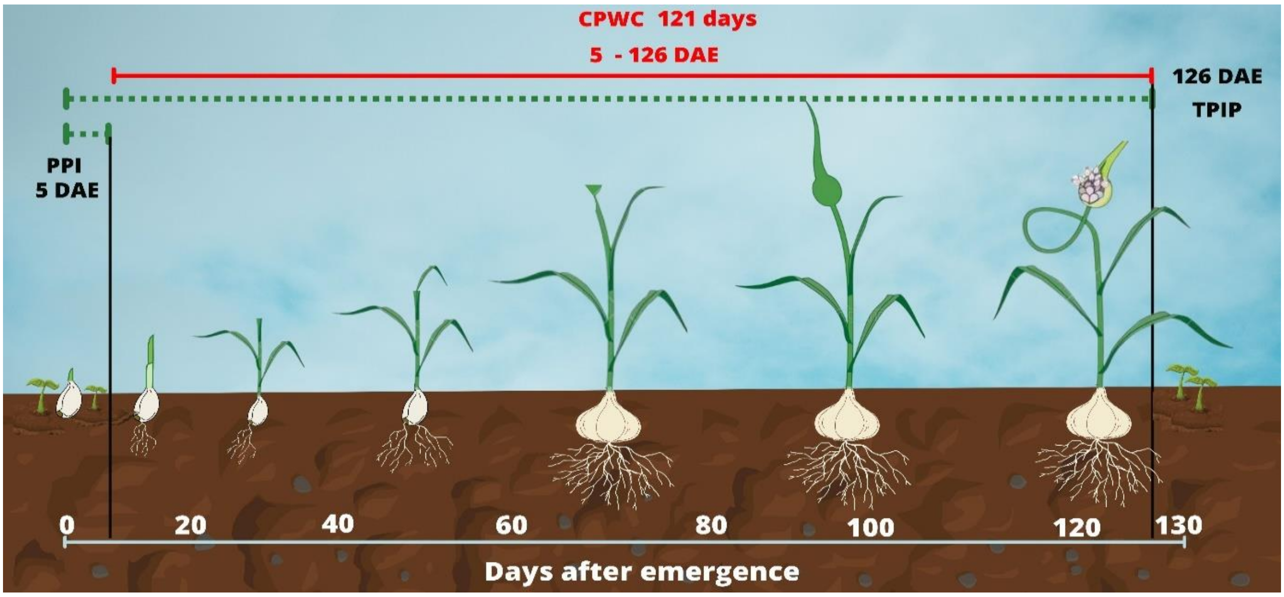

Figure 9. Illustration of periods of weed interference in a garlic crop, considering total bulb yield.

Conclusion

The research findings underscore the significant impact of weed interference on total and commercial bulb yields of garlic crops, specifically for the Ito and Chonan cultivars in the 2019 and 2020 growing seasons. Comparing garlic crops grown in the presence of weeds throughout the entire crop cycle to those grown without weeds, mean yield losses amounted to 26.6% for total bulb yield and 29.2% for commercial bulb yield. The critical period of weed control (CPWC) was consistently observed to commence at 5 or 6 days after crop emergence (DAE) and extend until 126 DAE. This period is of paramount importance as weed control within this time limit is essential to prevent adverse effects on garlic bulb yield. Implementing effective weed management strategies during the CPWC is crucial for garlic growers to optimize both total and commercial bulb production.

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