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Planting season alters the interference of weeds in the common bean

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Abstract

The common bean has social, economic, culinary, and environmental relevance. Considering its low competitive capacity and the intensive use of herbicides, methods such as planting time can help in weed management. To determine the effect of the planting season on controlling weeds affecting common beans, an experiment was conducted during the summer planting and another in winter planting . For that seven incrementing periods were implemented: 0-10, 0-20, 0-30, 0-40, 0-50, 0-60 and 0-80 days after bean emergence with coexistence of weeds and the same periods with control of weeds, which established 14 treatments in four repetitions, under a random block design. Weeds were analyzed using a phytosociological method and their dry mass with yield examined by regression. The non-linear regression analysis determined the pre-interference period (PIP), the critical period for interference prevention (CPIP) and the total interference prevention period (TIP). The relevant species were *Nicandra physaloides*, *Digitaria nuda* and *Raphanus raphanistrum*. The TIP was similar in both planting seasons. The CPIP was 38 and 33 days in summer planting and winter planting, respectively. The PIP had six more days in winter planting compared to summer planting. The higher dry mass in weeds reduced yield by 14.7 % in winter planting, in relation to the summer planting, but the reduction was faster in this season. Winter planting conferred a certain competitive advantage to the crop over some weed species, thus it could be suggested planting common bean in that season.

Keywords: competition; interference periods; *Phaseolus vulgaris* L.; phytosociology; sustainable weed management.
Abbreviations: CPIP_ critical period of interference prevention; DAE _days after emergence; PIP_ pre-interference period; RI_relative importance; SP_summer planting; TIP_total interference prevention period; WP_winter planting.

Introduction

The common bean (*Phaseolus vulgaris* L.) is a crop of economic, environmental, nutritional, and social importance in the world. Because beans can be cultivated in small areas, a high investment is not required, rather they improve soil conditions (it can be cultivated in rotations, and associations) and has a high protein content in grains and leaves (Muimba-Kankolongo, 2018). Thus, beans can be available to populations with limited economic resources without access to animal proteins. They are considered by nutritionists to be an almost perfect food because, in addition to protein, they contain fibers, complex carbohydrates, folic acid, iron, zinc, magnesium and potassium (Ribeiro et al., 2011) .

Agronomic and cultural characteristics make this crop an excellent alternative for smallholders, however, because it is highly dependent on nutrients, water and, susceptible to pest and disease, all production aspects must be well managed by the producer (Embrapa, 2021). Especially weeds because this crop has low competitive capacity and weeds can cause the serious damage. Baker et al. (2021) reported yield losses of around 80% and 100% during 2017/18 and 2018/19, respectively, in beans without weed control compared to the crop that grew free of weeds.

Interference periods are intervals in the cycle of a crop in which productivity losses may occur as a result of coexistence with weeds. Amaral et al. (2019) indicated three periods of interference: period before interference or PIP (period in which weeds can live with the crop without significant reduction in yield), total interference prevention period or TIP (a period after emergence in which the crop must be free of weeds so there is not a significant change in the performance or in other characteristics) and, a critical period for interference prevention CPIP (a period in which weed control is necessary).

Certain edaphoclimatic conditions can favor weeds or the cultivated plant, depending on how the interference of the weeds on the crop is altered. For example, cold places or seasons (minimum temperature of 5 ^{o}C) favor germination and the establishment of *Raphanus raphanistrum* (Kebaso et al., 2020), making it more prevalent than other species that prefer warmer conditions. In arid conditions, with temperatures in the range of 27-32 ^{o}C and even under drought, the expansion of *Sorghum halepense* is impressive (Peerzada et al., 2017), therefore the infestation levels are greater than in cold seasons. As a result, the interference periods under different planting times may also be different.

Because planting season is one of the most economical, safe and ecological strategies for weed management (Etminani et al., 2021), developing studies in weed science should contribute to make a more efficient and sustainable management of weeds. So, one way is by taking advantage of the most favorable conditions for the crop. The information is scarce since only two articles were found in the period 1971 to 2021 (Karavidas et al., 2022). Therefore, the objectives of the present study were to determine the effect of two planting times in bean on weed interference, as well as to characterize weeds that coexist with the crop and correlate their interference with yield.

Results

Weed community composition

In both, the plantings for summer or SP (2020) and winter or WP (2021), 17 species were identified that were common in both seasons. The species *Acanthospermum hispidum, Coronopus didymus, Raphanus raphanistrum, Senna obtusifolia, Sida rhombifolia, Portulaca oleracea, Nicandra physaloides, Commelina benghalensis, Cyperus rotundus, Eleusine indica, Digitaria nuda* and *Brachiaria plantaginea,* represented 35.3% of the total species in both years. The families with the highest percentage of species in SP and WP were Poaceae with 23.5% and 17.6%, respectively, and Asteraceae with 12% in both SP and WP.

Weed density in coexistence periods

In the SP, the maximum weed density (171.3 plants m^{-2}) was observed at 10 DAE, then decreased at 20 and, increased at 30 DAE, after that the density decreased until harvest (Figure 1A). *Nicandra physaloides* displayed the maximum number of individuals (85.3 plants m^{-2}) at 10 DAE and *Digitaria nuda* (55.8 plants m^{-2}) at 30 DAE (Figure 1A). In the year 2021 (WP), the maximum density of weeds (52.5 plants m^{-2}) occurred at 30 DAE, decreased until 50 DAE, then increased at 60 DAE and then decreased until the end of the cycle (Figure 1B). The species with the highest number of individuals were: *Nicandra physaloides* (26 plants m^{-2}) and *Digitaria nuda* (26.3 plants m^{-2}) at 40 and 30 DAE, respectively (Figure 1B).

In the SP, the average number of individuals per period of coexistence with *Nicandra physaloides* and *Digitaria nuda* were 64 and 35 plants m^{-2}, respectively, while in the WP the numbers were 13.8 and 11.9 plants m^{-2}, respectively. *Raphanus raphanistrum* showed an average density of 3.6 plants m^{-2} in the SP and 3 plants m^{-2} in the WP (data calculated from Figures 1A and 1B). In both seasons, the number of individuals showed a decreasing trend in the coexistence periods (Figures 1A and 1B).

Dry mass of weeds in coexistence periods

In the SP experiment, weeds had the highest accumulation of dry mass (358.6 gm^{-2}) at 80 DAE. *Nicandra physaloides* was the species with the highest dry mass (340.1 gm^{-2}) in the same period, and its presence suppressed other species (Figure 2A). In WP, the highest dry mass value in the weed community (494.8 g m^{-2}) was observed at 60 DAE in coexistence. *Raphanus raphanistrum* revealed the highest dry mass (312.8 g m^{-2}) among all species in the same period (Figure 2B). However, after 60 DAE, the dry mass of *Raphanus raphanistrum* and *Nicandra physaloides* decreased until the end of the experiment. The dry mass of *Digitaria nuda* showed an increase of 64% at 80 DAE, compared to 60 DAE (Figure 2B).

In general, the values of dry mass had an increasing trend as the periods of coexistence between weeds and crop also increased (Figures 2A and 2B).

Relative importance of weeds in coexistence periods

In SP, *Nicandra physaloides* exhibited the highest values of relative importance (RI) throughout the experiment (Figure 3A), while *Raphanus raphanistrum* showed decreasing RI values and showed its lowest value (2.4%) at 80 DAE (Figure 3A). In the WP, the maximum RI (69%) was found in the "other" species (*Portulaca oleracea, Amaranthus retroflexus, Commelina benghalensis,* among others) at 10 DAE, but after this period their RI only showed to decrease until the end of the cycle (Figure 3B). The RI of *Nicandra physaloides* got a maximum of 45.4 % at 40 DAE, decreased at 50 DAE and then increased in the way to 80 DAE (Figure 3B).

The average RI of *Nicandra physaloides* was higher in SP (44.4%) than in the WP (30%). *Raphanus raphanistrum* showed a significant increase in mean RI in the WP (26.4%) compared to SP (9.3%) (data obtained from Figures 3A and 3B).

Interference periods

In SP, 22 DAE took place before the weeds started to interfere with the crop (PIP). Control of the weed community was done up to 59 DAE to reach 95% of the treatment strength with permanent weed control (TIP). Thus, weed control was critical from 22 to 59 DAE, defining an interval of 38 days (Figure 4).

Yield in permanent absence of weeds was 2969.4 kg ha^{-1}, while bean plants living constantly with weeds dropped yield to 880.9 kg ha^{-1}, a decrease of 70.3% in relation to the treatment-free in the SP (Figure 4).

Regarding WP, a PIP of 28 DAE and a TIP of 60 DAE were determined. Therefore, the CPIP began at 28 DAE and ended at 60 DAE, for a period of 33 effective days (Figure 5).

There was a 34.6% reduction in yield for beans grown in the presence of weeds throughout the cycle (1121.4 kg ha^{-1}) compared to the treatment with permanent weed control (1715.2 kg ha^{-1}) in WP (Figure 5).

A 5-day reduction in CPIP and a 6-day increase in PIP were seen under WP conditions, compared to same periods in SP. Despite these differences, the TIP was practically the same in both seasons (Figures 4 and 5).

Influence of dry mass of weeds on yield of common bean

There was an exponential relationship between the dry mass of the infesting community and bean's yield in both seasons, showing lower yield values as the dry mass increased with a faster decrease in yield during the SP (Figure 6). In the absence of dry mass, yield in the SP was 38.4% higher than in the WP. In contrast, a higher dry mass accumulation generated a 14.7% yield reduction in WP compared to SP (Figure 6).

Discussion

Weed community composition

The weather conditions in 2020 and 2021 did not necessarily cause a diversification of the weed communities. Since these experiments were carried out in the same field, high numbers of common species were observed in both years. However, there was an influence of the season on

Table 1. Monthly climatic conditions in two common bean planting seasons, recorded at Agroclimatological Station - Department of Exact Sciences, FCAV/UNESP-Jaboticabal Campus, São Paulo, Brazil.

	Summer planting (2020)				Winter planting (2021)			
	July	August	September	October	April	May	June	July
Maximum temperature (°C)	29.74	29.49	34.42	34.22	29.52	28.65	05.27	26.14
Minimum temperature (°C)	14.40	13.93	17.88	19.74	15.83	14.69	13.88	9.94
Precipitation (mm)	0.00	0.12	0.54	0.79	1.05	0.21	0.75	0.00
Insolation ratio *	0.85	0.76	0.75	0.48	0.78	0.66	0.72	0.87

* Calculations based on the n/N ratio, where: n= insolation (hours), N= photoperiod (hours)

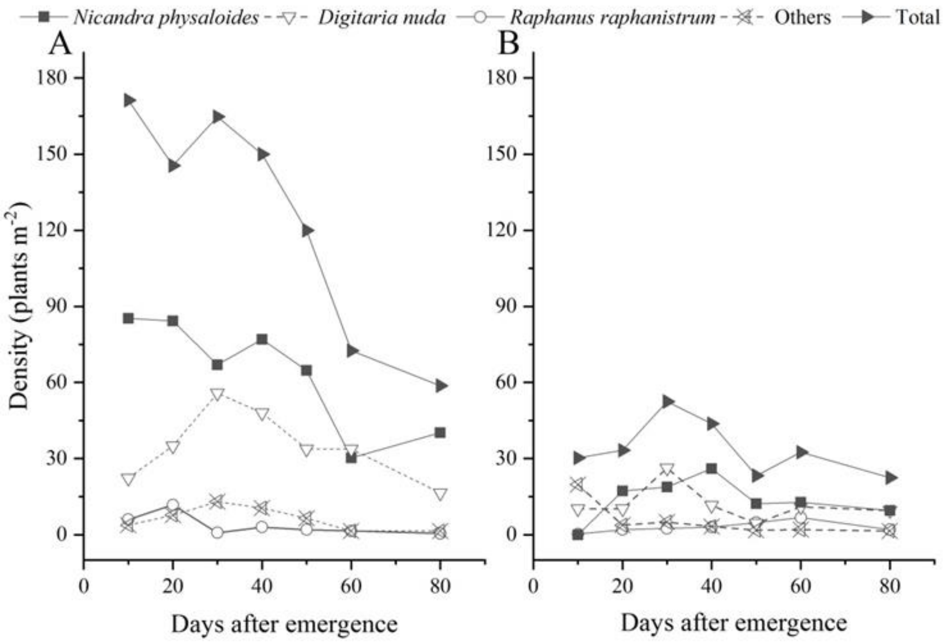

Figure 1. Density of weeds in coexistence periods in summer planting (A) and in winter planting (B).

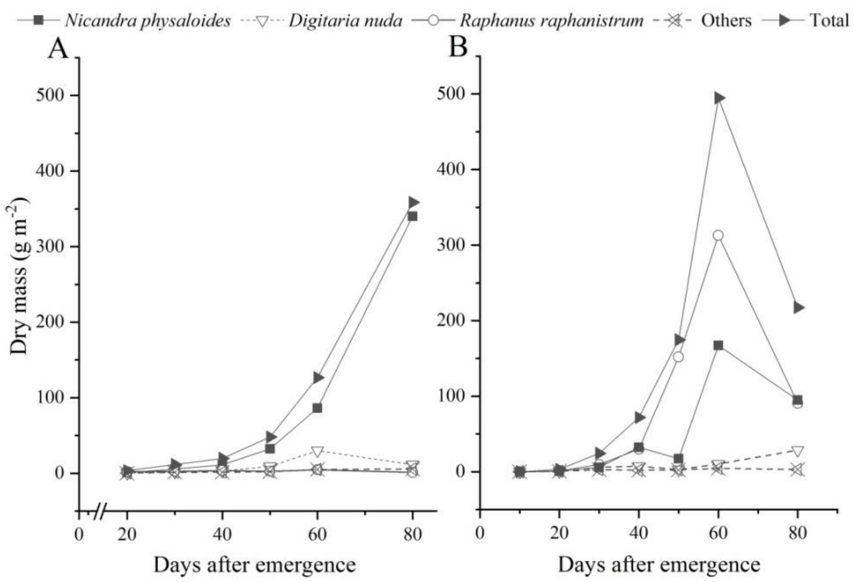

Figure 2. Dry mass of weeds in coexistence periods in summer planting (A) and in winter planting (B).

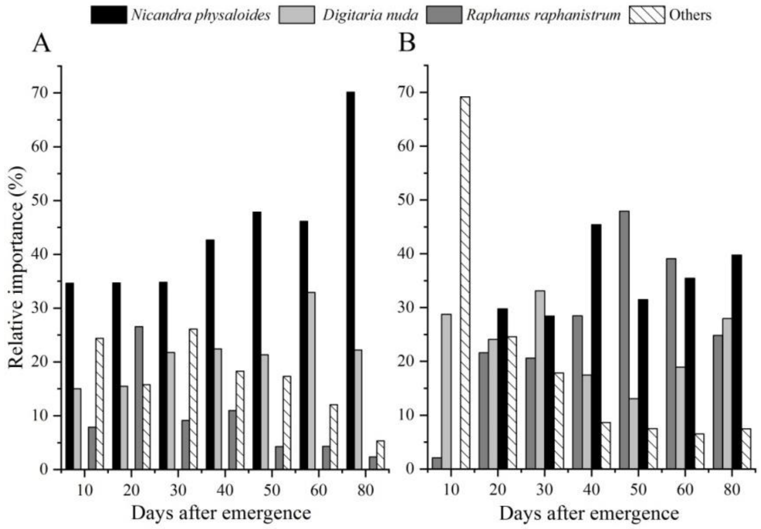

Figure 3. Relative importance of weeds in coexistence periods in summer planting (A) and in winter planting (B).

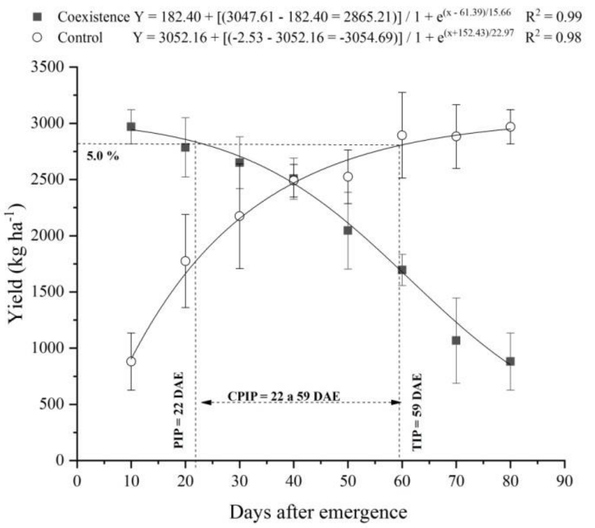

Figure 4. Interference periods of weeds in the common bean during summer planting, considering a 5% yield loss. PIP: pre-interference period, CPIP: critical period of interference prevention, TIP: total interference prevention period.

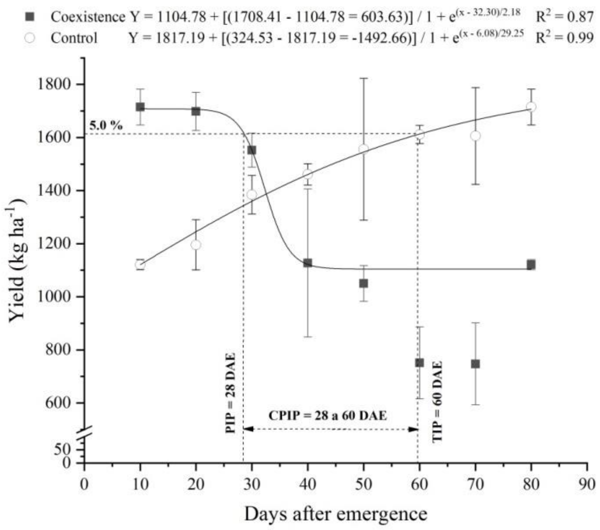

Figure 5. Interference periods of weeds in the common bean during winter planting, considering a 5% yield loss. PIP: pre-interference period, CPIP: critical period of interference prevention, TIP: total interference prevention period.

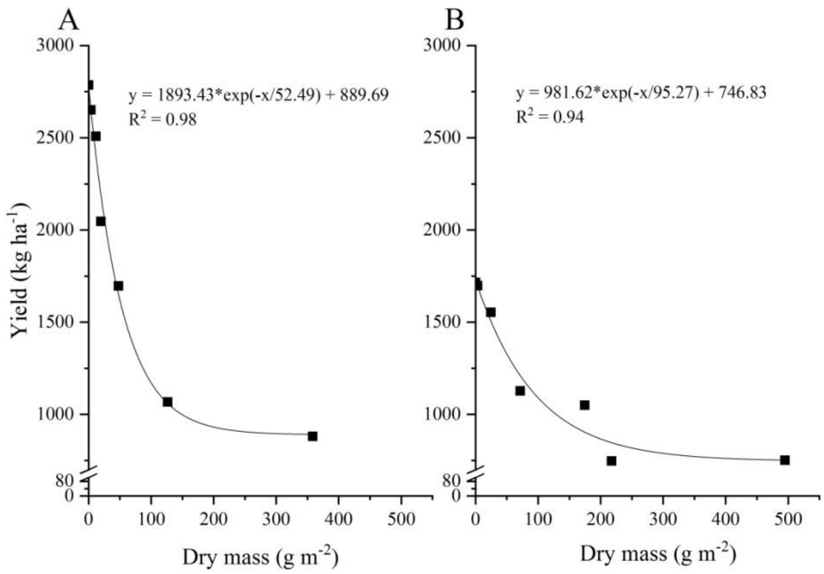

Figure 6. Influence of dry mass of weeds on bean yield in summer planting (A) and in winter planting (B).

prevalence, in terms of density or dry mass levels of the species. For instance, *Nicandra physaloides* was more important in the SP due to better and greater germination rates in warm conditions (CABI, 2022).

The Poaceae family stood out in contribution of species because this family holds a large number of them, with a broad distribution around the world. This family has about 11000-12000 species adapted to the most diverse conditions, such as forests, deserts, from the poles to the equator and from the sea level to high altitudes (Kellogg, 2015) .

Weed density in coexistence periods

The decreasing trend in the number of weeds is explained by a greater competition between the crop and other species in an environment with increasingly limited resources. Therefore, at the end of the cycle there were few individuals left, but they were the most competitive.

The lower number of individuals of *Nicandra physaloides* in the WP was caused by lower temperatures and probably to a low microbial activity in the destruction of the integument (Qasem, 2019), a structure responsible for the physical dormancy reported in this species (CABI, 2022). The lower amounts of organic matter and lower temperatures in the WP may be the reason for a lower amount and/or activity of microorganisms in the seed coat of *Nicandra physaloides.*

The lower density of *Digitaria nuda* in the WP was because the maximum and minimum temperatures were close to 25 and 10°C, respectively, values in which *Digitaria nuda* had the lowest germination rates (less than 25%), regardless of the treatment used to overcome latency (Hugo et al., 2014).

Although there were a low number of *Raphanus raphanistrum* individuals, it was large enough to exert a strong interference in cultivation of bean. Bressanin et al. (2013) confirmed that only a density of 6.6 plants m^{-2} of this species was able to affect number of pods, leaf area, dry mass of the leaves and fresh mass of pods in common beans.

The irregularity of weed density throughout the experiment is explained by stunned germination, an attribute in weeds that allows germination and establishment for a certain number of seedlings to occur at different times as dormancy is overcome, this makes very difficult to predict the number of weeds (Qasem, 2019)

Dry mass of weeds in coexistence periods

The planting time that most favored the accumulation of dry mass in *Nicandra physaloides* was the SP, because of the higher temperatures and luminosity (as related to insolation or sunlight) that allowed higher photosynthetic rates. Consequently, the species have optimal grow and development in this environment, promoting soil exploration and nutrient extraction. Given a great extractive capacity, among other characteristics, De Matos et al. (2018) suggested the potential use of *Nicandra physaloides* as green manure.

Even at low density, *Raphanus raphanistrum* showed high values of dry mass in WP, evidencing thus an excellent nutrient extractive capacity under cold conditions. Therefore, it is considered a superior plant in competition for water, light, nutrients and biomass accumulation, when compared to other crops (Kebaso et al., 2020). Coincidentally, Parreira et al. (2012) reported that *R. raphanistrum* stood out in content of dry mass in periods of coexistence with common beans in winter planting, compared to the other species.

During increasing periods of coexistence, although the density of the weed community decreased, its dry mass increased due to more competitive individuals that suppressed others (Odero and Wright, 2018 ; Lacerda et al., 2020).

Relative importance of weeds in coexistence periods

A greater relevance of *Raphanus raphanistrum* in the WP compared to the SP was due to a better adaptation to the lower temperatures of the WP. Barroso et al. (2010) also reported in common beans that the winter-spring season was more favorable for the development of *R. raphanistrum* compared to summer-autumn. Kebaso et al. (2020) stated that this species can have a rapid establishment under the minimum temperature of 4.5 °C in a vegetative stage.

On the other hand, *Nicandra physaloides* and *Digitaria nuda* were the species in the season with the highest temperature and luminosity (SP), compared to the WP, which allowed them to suppress other species throughout the experiments. In addition to the direct interference it exerts, Bellé et al. (2017) reported that *N. physaloides* is a host for the nematode *Meloidogyne incognita* that infects beans, the same is possible in *D. nuda* since it was found that two species of genus *Digitaria* were alternate hosts of the nematode. Hence, both species should be considered priority in an integrated management of weeds affecting common bean.

Nicandra physaloides was the most relevant species in both seasons, it was largely responsible for the interference in common beans. Uljol et al. (2018) and Amaral et al. (2019) also reported high RI values for this species in periods of coexistence in pepper and sugarcane which evidenced its great infesting capacity in different agroecosystems.

Interference periods

The most important differences were the duration of the PIP and CPIP, since the TIP was practically the same in both seasons. Due to low temperatures, weed pressure (mainly *Nicandra physaloides*) was lower in the WP compared to the SP at the initial periods, so the crop was able to live longer with the weeds without experiencing significant yield losses, which resulted in a longer PIP in WP.

Climate influenced species in terms of density, frequency and dry mass, helping some and harming others. Barroso et. al (2010) worked under conditions that were similar to our study and found a high dry mass of weeds in winter planting (17.7 g m^{-2}) and low dry mass in summer planting (6.6 g m^{-2}), evidence of the effect of climate on the weed communities in common bean.

On the other hand, CPIP was shorter in WP than in SP indicating that the crop was less sensitive to weed interference in WP. Although the crop showed a higher competitive advantage, yield was lower in WP due to lower temperatures. Values around 21 °C at night and 29 °C during the day are suitable for promoting high yield in common bean (Da Silva et al., 2014) . In our study, in 2021 (WP) the mean minimum and maximum temperatures were 13.5 and 27.8 °C, respectively, and in 2020 (SP) they were 17 and 31.9 °C, respectively. Therefore, these values were found to be far more apart from the ideal range, especially minimum temperature in WP.

During flowering and pod filling, there were eight days with minimum temperatures below or close to 12°C, which caused floral abortions and affected floral openings. According to da Silva and Heinemann (2021) air temperatures below 12°C can trigger flower abortion and decrease in yield. In addition, Bliss (1980) stated that at temperatures below 15°C the flowers may not open normally, causing problems for cross-pollination in common beans. Although bean is an autogamous species, pollination by insects takes place and it can improve productivity and quality of the grain (Elisante et al., 2020) .

Additionally, lower luminosity in the year 2021 (WP), expressed in terms of the solar insolation ratio, decreased photosynthetic rate affecting the size and weight of grains observed at harvest (data not shown), compared to the grains obtained in the SP.

Influence of dry mass of weeds on bean yield

Considering sanitary management, water supply, fertilization and other appropriate and timely cultural practices in both seasons, the highest yield in SP without dry mass of weeds was higher than in WP. It was also in the absence of weeds, mainly because of climatic conditions at planting times. The WP was less favorable for the common bean. Under similar conditions of location, row spacing, density and cultivar similar in our study, Parreira et al. (2012) found a yield of less than 1700 kg ha^{-1} in the absence of weeds in the WP, a value below the potential yield of the cultivar used (3900 kg ha^{-1}). In another experiment, Barroso et al. (2010) reported a 38.9% reduction in yield of common bean during winter planting in relation to summer planting, under an always weed-free treatment.

Although the climatic conditions of the WP gave the crop a certain competitive advantage against some species such as *Nicandra physaloides*, it was not reflected in a high yield because of the larger influence of climate which did not favor winter bean or a third crop. According to Dapaah et al. (2000), the planting season is a critical factor in determining the environmental conditions at the time of planting, anthesis, pod filling and bean drying, which can define the success of the crop.

The influence of weed's dry mass on the speed of yield loss was less in the WP, specifically, in the case of the WP, the yield decreased more slowly than in the SP while the dry mass of weeds increased. So, in this correlation, it is confirmed that the climate of the WP provides a certain competitive advantage to the crop, making it less sensitive to increases in the dry matter of weeds compared to the SP.

Materials and methods

Soil and environment classification and geography of the region

Two experiments were carried out in a field at the São Paulo State University Jaboticabal, São Paulo (21º15'17''S, 48º19'20''W and 590 m altitude): the first from July to October 2020 (summer planting) and the second from April to July 2021 (winter planting). The soil was classified as Red Eutrophic Latosol, with a clay texture (total sand=210 g kg^{-1}, silt =390 g kg^{-1}, clay=400 g kg^{-1}), pH($CaCl_2$)=5.4 and 4.6, organic matter=17 and 13 g dm^{-3}, P(resin)=16 and 21 mg dm^{-3}, K=0.6 and 4.7 mmol $_c$ dm^{-3}, Ca=20 and 11 mmol $_c$ dm^{-3}, Mg=9 and 7 mmol $_c$ dm^{-3} and H+Al=27 and 23 mmol $_c$ dm^{-3}, the first value corresponding to summer planting (SP) and the second to winter planting (WP).

Climate in the region is classified as Cwa type, according to Köppen classification, with implies rains in the summer and relatively dry winters (Andre and García, 2015). Climatic data for both years are indicated in Table 1.

Experimental design and treatments

The experimental design used was randomized blocks, with 14 treatments in four repetitions in both seasons. The treatments included seven increasing periods of control and seven increasing periods with coexistence with weeds, totaling 14 treatments The periods were: : 0-10, 0-20, 0-30, 0-40, 0-50, 0-60 and 0-80 days after emergence (DAE) of beans. In the control periods, weeds were controlled until the end of the given period, then they were allowed to coexist with the crop until the end of the cycle. In the periods of coexistence, the weed community was maintained for the same length of the periods, then manual controls were done after each period and continued until harvest. The experimental unit was a plot of five lines 5 m long, eliminating a line on each side and 1 m from the end as borders.

Conduction of study

Soil preparation was done in conventional ways through chiseling, plowing and harrowing. The cultivar used was TAA Dama (with a type III indeterminate growth habit). This was planted on July 27, 2020 (SP) and April 7, 2021 (WP) at a density of 10 plants m^{-1} and spacing of 0.45 m between lines. The first fertilization was done at planting with 200 kg ha^{-1} of formula 28-8-16 and the second was in stage V4, applying 144 kg ha^{-1} of nitrogen. Pests and diseases were controlled in a timely manner. The harvest was carried out on October 26, 2020 (SP) and July 6, 2021 (WP), allowing the plants to dry until the grains attained adequate moisture for mechanical threshing.

Characteristics measured

Weed evaluations were made at the end of each coexistence period and at harvest in the control periods. The assessments were done using a frame of 50 cm per side which was launched twice on the center lines of each treatment. In the area determined by the square, weeds were identified, counted, and placed in a forced circulation oven for 72 hours at 70 °C to determine dry mass. With these results, relative frequency (presence of the population in terms of coverage of the area), relative density (presence of the population in numerical terms), the relative dominance (accumulation of dry mass), the index value of importance and the value of relative importance (reflecting the relevance of a population) were estimated according to the methodology of Mueller - Dombois and Ellenberg (1974). At harvest, moisture of bean grains was measured with a portable device, and then it was weighed using a precision scale to calculate yield, correcting weight for a moisture content of 13% and expressing the results in kg ha^{-1}.

Statistical analysis

For each planting season, yield data were subjected to nonlinear regression analysis using Boltzmann's sigmoidal model, according to Equation 1.

(1)

$$Y = \frac{(A1 - A2)}{1 + e^{(X - X0)/dx}} + A2$$

Where: Y = grain yield in kg ha^{-1} ; A1 = maximum yield in treatments with control throughout the cycle; A2 = minimum yield in treatments without control throughout the cycle; X= upper limit of the period of coexistence or control in days; X_0 = upper limit of the coexistence period, corresponding to the mean value between the maximum and minimum performance; dx = rate of loss or gain in performance depending on the period of coexistence or control.

With the equations of the sigmoidal model, the interference periods were determined considering a 5% arbitrary loss of yield, in relation to the treatment with weed control throughout the cycle. Additionally, regression analyzes of the weed's dry mass in the increasing periods of coexistence with bean productivity were carried out. All analyzes were performed using OriginPro® software.

Conclusion

Winter planting conditions gave a certain competitive advantage to the crop, increasing the duration of the pre-interference period and decreasing the critical period of interference prevention, compared to the same periods of interference in summer planting .

The relevant species of the weed community in terms of density, frequency and dry mass were *Nicandra physaloides* and*, Digitaria nuda* in summer season and *Raphanus raphanistrum and Digitaria nuda in winter planting*.

The decrease in crop yield was exponential when the dry mass of the weeds increased. The decrease was faster in the summer planting in comparison to the winter planting.

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