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Selectivity of Clomazone Applied in Pre-emergency of the Carioca Bean in Different Soils and Water Conditions

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Abstract

There are few registered herbicides with selectivity and efficiency in the control of weeds in bean. The objective of this work was to evaluate the efficacy and selectivity of clomazone applied in pre-emergence of the carioca bean under different water conditions. The experiment was conducted in a greenhouse, in a randomized block design, arranged in a 4 x 2 x 3 factorial scheme, with four repetitions per treatment. Factor A allocated the doses of the herbicide (0, 126, 252 and 378 g i.a. ha^{-1}), factor B the types of soil (clay and sandy) and factor C the water availability in the soil (50, 80 and 100% of field capacity). The variables evaluated were phytotoxicity, plant height and emergence at 7 and 14 days after application. At 21 DAA, stem diameter, photosynthetic rate, internal CO2 concentration, transpiration rate, stomatal water vapor conductance, carboxylation efficiency, efficient water use, leaf area and dry mass of the aerial part of the crop were also evaluated. The results obtained show that phytotoxicity at 21 days after herbicide application was less than 60% for all soil water availabilities, both for clay and sandy soils at a dose of 378 g a.i. ha^{-1}. The leaf area showed the best results for the sandy soil associated with higher humidity, regardless of the dose of clomazone used. The physiological variables also showed better results when soil moisture was at 100%.

Introduction

The common bean (*Phaseolus vulgaris L*) is a specie widely consumed and produced worldwide (Stähelin et al., 2010; Conafer, 2023). The bean culture is essential for its economic, social, and cultural aspects. This legume is a fundamental component of the diet in different countries, providing proteins, iron, lipids, magnesium, potassium, and carbohydrates (Lovato et al., 2018; Viecelli et al., 2021).

Brazil is the world's largest producer of common beans (Phaseolus vulgaris L.). Due to its wide edaphoclimatic adaptation, its cultivation happens in almost all Brazilian states at different times and harvests (Conab, 2023). One of the main biotic factors that cause interference in bean production is weed infestation. Weeds compete with the crop mainly for water, light, and nutrients, significantly affecting grain development and yield (Cury et al., 2013; Parreira et al., 2014; Galon et al., 2018). Chemical management with herbicides is the most used for weed control due to the ease of application, effectiveness, and lower cost compared with other control methods (Cury et al., 2011; De Mesquita et al., 2017; Galon et al., 2017a).

The use of herbicides in the pre-emergence of crops has demonstrated effective control of weeds and increased grain yield of pinto and “small red Mexican beans” (Sikkema et al., 2008), caupi beans (Silva et al., 2014) and black beans (Galon et al., 2017b). However, there are few registered herbicides for controlling weeds in common bean crops, especially in the pre-emergence of the crop (De Mesquita et al., 2017; Agrofit, 2023). It is due to the low investment in research and development of new products or even the lack of cultivars more tolerant to herbicides in Brazil (De Mesquita et al., 2017). The scarcity of products recommended for the common bean crop favors unregistered phytosanitary products for the culture, causing phytotoxicity problems for the culture and toxicological and environmental issues.

The sorption, leaching, and degradation processes, as well as physical, chemical, and biological processes that occur in the soil, influence the action of pre-emergent herbicides (Alves et al., 2004; Szmigielski et al., 2009; Silva et al., 2021). Thus, soil characteristics such as moisture, texture, structure, and porosity, among other factors, are directly related to the persistence period of the herbicides, as well as their residual capacity (Bedmar e Gianelli, 2014; Silva et al., 2021), which can influence the efficiency of weed control and also the selectivity of crops.

The change in soil water availability can modify the process of retention, transport, and transformation of herbicides in the soil, determining changes in the selectivity of herbicides for cultivated plants (Silva et al., 2007). Monqueiro et al. (2012) point out that herbicides applied to the soil surface dissipate with no difficulty, especially if there is a prolonged dry period after application.

The herbicide clomazone is a carotenoid biosynthesis inhibitor recommended in the pre-emergence of crops such as cotton, rice, sugar cane, cassava, and soybeans, but it has shown potential for use in bean cultivars (Takano et al., 2012; Golden et al., 2017; Harrison et al., 2015). Carotenoids are photoprotective pigments, and when inhibited and degraded, they no longer help in photoprotection, allowing the photo-oxidation of membranes and proteins, which can cause plant death (Ferhatoglu; Barrett, 2006; Rodrigues; Almeida, 2018). The main symptom caused by clomazone is leaf depigmentation, that is, the loss of the green color, making the newer tissues white or with violet or pink tones (Silva et al., 2007).

In some cases, the application of pre-emergent herbicides can cause phytotoxicity to cultivated species, which increases, in general, the greater their availability in the soil solution (better absorption by plants) (Ribeiro Jr. et al., 2018). The pre-emergence application of clomazone affected the performance of the watermelon crop (Harrison et al., 2011) but did not change the soluble solids content and potato productivity (Luz; Fonseca; Duarte, 2018).

The development of research is relevant to obtain information on the behavior of herbicides in different types of soils with contrasting characteristics and distinct conditions of water availability. The present work presents two main hypotheses. The first hypothesis is that the application of the herbicide clomazone in soil with less clay and organic matter would cause more damage to bean plants. And the second hypothesis is that the increase in water availability, both in soil with a clayey and sandy texture, reduces the phytotoxicity generated by clomazone to bean plants due to the displacement of the herbicide to the zone farther from the root system. Therefore, the objective of the work is to evaluate the selectivity of clomazone applied in the pre-emergence of carioca beans in two types of soil and under different water conditions.

Material and Methods

Cultivation conditions and experimental design

The experiment was carried out in a greenhouse at the Universidade Federal da Fronteira Sul (UFFS), Campus Erechim, RS (latitude -27º 43' 38.82" S, longitude - 52º 17' 02.72" W, altitude 783 m), between

November and December 2019. Initially, the collection of soils with sandy and clayey textures was in two different places. The sandy soil, characterized as Dystrophic Red-Yellow Argisol (Santos et al., 2018), was collected at the Experimental Station of the Paraná Development Institute (IDR/PR) in the municipality of Paranavaí, PR (latitude - 23° 05' 00 " S, longitude - 52° 27' 32" W, altitude 445.22 m). The clayey soil, characterized as humic Aluminoferric Red Latosol (Lima; Lima; Melo, 2012), was collected in the municipality of Erechim, RS (latitude - 27º 38' 03" S, longitude - 52º 16' 26" W, altitude 783 m). Clay soil has a higher clay content than sandy soil. The physicochemical characteristics are in Table 1. After collection, the soils were dried in the shade, sieved with a 4 mm diameter sieve, and placed in plastic vases with a capacity of 3 L, lined internally with voile fabric, in a greenhouse.

Table 1 - Physical-chemical characteristics of soil samples from the municipalities of Paranavaí and Erechim used in the experiment as sandy and clayey soil, respectively.

Soil	Sand	Silt	Clay	OM	CEC	SB	V	Sat. Al
	(%)	(%)	(%)	mg dm^{-3}	$cmol_c\ dm^{-3}$	$cmol_c\ dm^{-3}$	(%)	(%)
Paranavaí	85.80	1.20	13.00	16.08	5.45	3.26	59.82	
Erechim	5.10	22.90	72.00	44.23	16.77	10.56	62.97	
Soil	SMP	Al	H+Al	Ca	Mg	K	P	pH
	index	———		$cmol_c\ dm^{-3}$	———		$mg.dm^{-3}$	$CaCl_2$
Paranavaí	7.1	0.0	2.19	1.5	1.5	0.26	11.39	5.1
Erechim	5.7	0.0	6.21	5.8	4.1	0.66	10.05	5.0

CEC, cation exchange capacity. OM, organic matter. SMP, Shoemaker, McLean, Pratt method, P-Mehlich method, Ph CaCl2: 1:2,5...

The experimental design used was randomized blocks arranged in a 4 x 2 x 3 factorial scheme with four replications. Factor A was constituted by doses of clomazone herbicide (0, 126, 252, and 378 g ai ha-1), Factor B was allocated to the two types of soil (sandy and clayey), and C was composed of water regimes (50, 80, and 100% of θCC).

Five seeds of common bean (*Phaseolus vulgaris L.*) of the carioca type, cultivar IAC Milênio (IAC, Campinas, Brazil), were sown in each pot at a depth of 3 cm. Immediately after sowing, the herbicide clomazone (Gamit® 360 CS, FMC Química do Brasil Ltda., Campinas) was applied. The herbicide application was in doses of 126, 252, and 378 g a.i. ha-1 corresponding to 0.5x, 1.0x, and 1.5x of the reference dose (252 g i.a. ha-1) based on a study by Galon et al. (2017b). The herbicide was applied using a pressurized CO2 backpack manual sprayer (Herbicat®, Catanduva, Brazil) equipped with a 2 m long boom and attached to this 4 XRTeejet® (XR110/02-VP) tips, spaced apart 0.5 m apart, which

provided 200 L ha-1. Sprinkling was carried out directly on the soil, keeping the boom at 0.5 m from the top of the pots.

The moisture at the field capacity (θCC) of each soil was used as a reference to keep the plants in the greenhouse. The θCC was obtained at a tension of 10 kPa (Cassel and Nielsen, 1986; Reichardt, 1988) using a tension table that determined the volumetric soil moisture (Embrapa, 1997). Soil moisture was determined using a time-domain reflectometry (TDR) probe (standard model 6005L, Soilmoisture Equipment Corp., Santa Barbara, USA) coupled to a MiniTrase TDR moisture meter (Soilmoisture Equipment Corp., Santa Barbara, USA). The measurement of field capacity started before sowing for the imposition of water regimes at 50, 80, or 100% of the θCC at the time of sowing, according to the scale proposed by Bernardo (2005).

Plant emergence and phytotoxicity

The evaluations of the number of emerged bean plants were carried out at 7 and 14 days after application (DAA) and those of phytotoxicity at 7, 14, and 21 DAA. For the evaluation of phytotoxicity, percentage scores were attributed zero (0%) to treatments with no phytotoxicity and one hundred (100%) to maximum phytotoxicity, according to the methodology proposed by Sbcpd (1995).

Physiological characteristics

At 21 DAA, it evaluated the photosynthetic rate (A, μmol m-2 s-1), stomatal conductance (gS, mol m-2 s-1), transpiration rate (E, mol m-2 s-1), internal CO2 concentration (Ci, μmol mol-1). These variables were determined in the middle third of the last fully expanded leaf, using an infrared gas analyzer (IRGA, LCA PRO, Analytical Development Co. Ltd, Hoddesdon, UK) between 8:00 and 11:00 under constant photosynthetic flux density (PPFD, 1000 μmol photons m-2 s-1), atmospheric CO2 concentration (Ca) (~ 400 μmol mol-1), and ambient temperature (± 26 ºC) and relative humidity (± 80%). Carboxylation efficiency (EC, mol CO2 m-2 s-1) and water use efficiency (EUA, mol CO2 mol H2O-1) were calculated from the ratio A/Ci and A/E, respectively.

Morphological characteristics

At 21 DAA, it evaluated Plant height (AP, cm), plant stem diameter (DC, mm), leaf area, and shoot dry mass (DM, g). The leaf area of the plants was determined using a leaf area integrator (LI-COR Li-3000C). To determine the DM, the plant material from the aerial part of the plants was collected and dried in an oven with forced air circulation (TE-394/4, Tecnal, Piracicaba, Brazil), at 65±5° C, until reaching a constant weight.

Statistical analysis

The data were submitted for analysis of variance by the F test ($p < 0.05$). If there is significance, the Tukey test was applied. The ExpDes.pt package (Ferreira; Cavalcanti; Nogueira, 2018) and R software

(Core Team R, Vienna, Austria) analyzed the data. The SigmaPlot v 12.0 program (Systat Software, Inc., Gemany) contributed to the generation of images.

Results and Discussion

Bean exposure to clomazone doses in different water regimes affected emergence, phytotoxicity, and physiological and morphological characteristics in sandy and clayey soils (Figs. 1, 2, 3, and 4).

The emergence of bean plants started at 5 DAA (data not shown). At 7 DAA, in sandy soil, it was possible to observe a large number of seedlings emerged in the treatments with the highest moisture contents (80 and 100% of field capacity) and the lowest doses of clomazone (0, 126, and 252 g a.i. ha^{-1}) (Fig. 1). In clayey soil, the results were similar to those obtained in sandy soil, but emergence was higher only in the highest moisture levels and in the control treatments and with the lowest dose of clomazone (126 g a.i. ha^{-1}) (Fig. 1).

Lower water availability negatively affected the emergence of bean plants in the two evaluated soils, including the control without clomazone. Water availability at the beginning of the germination process is essential to determine the success of plant growth (Ribeiro et al., 2015). During germination, water induces the activation of enzymes and assimilation of nutrients present in reserve tissues that are important for the development of the embryo and the entire seedling (Bewley et al., 2013; Guimarães et al., 2013; Martins Vieira et al., 2016).

Differences in emergence between field capacity percentages were reduced with the use of the highest dose of clomazone (378 g a.i. ha^{-1}), probably because the greater water availability in the soil increases the process of clomazone absorption by bean plants, increasing the action of the herbicide and with consequent accentuated reduction of emergence with the use of higher doses of the product. The herbicide clomazone is quickly absorbed by the roots and hypocotyl of plants in dicotyledonous species, and the translocation of the product occurs through the xylem (Vencill et al., 2002). The difference in water potential between plant tissues is considered the driving force of herbicides that translocate through the xylem (Vidal, 2002), and the higher water availability in the soil accentuates the differences in water potential between the root zone and the interior of the plant, increasing the movement of herbicides to young plant tissues. Recent works have reported that bean seeds are sensitive to herbicides, such as glyphosate (Helander et al., 2019) and chlorophenols (Pérez-Portuondo et al., 2021), proving to be a sensitive crop to herbicides when compared to other crops cultivated species.

At 14 DAA, with water regimes at 80 and 100% CC, bean emergence was resumed. In control, without clomazone application, the increase in emergence was more pronounced in clayey soil, compared to sandy soil, probably due to the greater water retention capacity provided by this soil, which causes greater seed imbibition. Regarding the treatments with clomazone, at 14 DAA, there was also emergence recovery at higher doses, in both soils, compared to the evaluation carried out at 7 DAA, which may be due to the increase in the metabolization capacity of the herbicide molecules. Clomazone sensitivity in

plants is influenced by the activity of clomazone metabolism. Multiple and complex oxidative pathways are associated with its metabolism, where cytochrome P450 monooxygenases (P450s) play an essential role in the activation and inactivation of clomazone (Nandula et al., 2019). The herbicide clomazone is cleaved inside soybean plants, and *Abutilon theophrastii* forms more polar metabolites, considered the principal metabolic process of this herbicide in these species (Weimer; Balke; Buhler, 1992). *Echinochloa phyllopogon* plants hydroxylated mainly with the isoxazolidinone ring of clomazone show higher clomazone hydroxylation activity in resistant plants than in susceptible plants (Yasuor et al., 2010), and there is evidence of the involvement of the CYP81A gene that encodes the cytochrome enzyme P450 on clomazone metabolism in this species (Guo et al., 2019).

Sandy soil allows for higher herbicide leaching compared to clayey soil - it justifies the lower phytotoxicity in this type of soil. It was also observed by Inoue et al. (2007) and Melo et al. (2010) when studying isoxaflutole, an herbicide belonging to the identical mechanism of action as clomazone. Clomazone has a high solubility in water (1,100 mg L^{-1} at 25°C) and Koc (adsorption coefficient) ranging from 150 to 562 cm^3 g^{-1}, characteristics that favor high leaching in the soil (Zanella et al., 2008).

In plants grown in clayey soil, it was observed that emergence in treatments with 80 and 100% of field capacity was similar to the control treatment, only with the lowest dose of clomazone, 126 g a.i. ha^{-1} (Fig. 1), with less emergence of bean plants exposed to higher herbicide doses. Clay soil tends to retain more water and, consequently, store more herbicide in the clay soil, increasing the availability of water and herbicide for the seeds (Pereira et al., 2018). High clayey soils were previously characterized as having a greater capacity to retain herbicide molecules in colloids, as verified with isoxaflutole (Lin et al., 2002), atrazine (Novais et al., 2019), and metsulfurom-methyl (Guerra et al., 2020).

As for the toxicity of clomazone to bean seedlings, at 7 and 14 DAA, the influence is more with the water availability on the action of clomazone in sandy soil is observed, compared to clay soil (Fig. 2). In sandy soil, under the three water conditions, increasing the toxicity to seedlings was proportional to the increase in herbicide dose. In clayey soil, however, there was an increase between the lowest dose (126 g a.i. ha^{-1}) and the others, with little difference in toxicity between the intermediate and higher doses. It occurred because, in sandy soil, the level of toxicity at 7 and 14 DAA of the highest dose (378 g a.i. ha^{-1}) to bean plants were higher when compared to the toxicity in clayey soil.

At 21 DAA, for the reference dose (252 g a.i. ha^{-1}), the phytotoxicity varied between 20 and 35%, considering the two types of soils and the three water availability. For the highest dose of clomazone (378 g a.i. ha^{-1}), although it was possible to verify a partial recovery of the toxicity of the bean plants, the levels were still between 43 and 60% in the highest (100% CC) and lower water availability (50% CC) of sandy soil; and, between 25 and 53% of phytotoxicity in clayey soil with 80 and 50% CC, respectively (Fig. 2).

At 21 DAA, there was higher phytotoxicity in the plants the more intense the water restriction was (Fig. 2). It can be attributed to the greater water demand of the plants as their development progresses,

which intensifies competition for water and nutrients, especially in treatments with less water availability. Water stress can compromise several functions in plants, which include defense mechanisms against the action of herbicides (Arteaga et al., 2020), and the unlike effects of water stress can contribute to the increase of the toxic effects of clomazone, compromising plant development. Clomazone was described to cause low toxicity to cotton plants, with only 9% injury when applied at a dose of 1,250 g ha-1 in soil with 39% clay (Dan et al., 2011), and 6% toxicity in black bean plants cultivar BRS Campeiro (Galon et al., 2017b). Despite finding low toxicity of clomazone for bean plants and high control of weeds *Digitaria ciliaris* and *Urochloa plantaginea*, Galon et al. (2017b) observed a 31.4% reduction in bean grain yield. In addition, severe effects of phytotoxicity related to the application of clomazone have been reported in cassava plants (Manihot esculenta) (Fontes; Oliveira; Morais, 2021), and isoxaflutole, a herbicide that inhibits the synthesis of carotenoids, in “mungbean” (Vigna radiata) (Mahajan; Chauhan, 2021). Phytotoxicity is linked to the type of soil and moisture. It can vary according to the cultivar used and be related to the number of reserves present in the seeds and the determinant of the plants' recovery capacity (Takano et al., 2012; Viecelli et al., 2021). Many herbicides or even crop species, sometimes the direct effect of phytotoxicity is not observed, can exert direct or indirect effects on plant growth and development, causing changes in physiological and metabolic processes, causing intoxication, dysregulation of defense mechanisms, oxidation cells, changes in nutrient absorption, among others (Rizzardi et al., 2003; Galon et al., 2015; Bari et al., 2020).

Regarding the physiological variables, it was also possible to verify more severe damage caused by clomazone in bean plants under higher water restriction (Fig. 3). In sandy soil, with underwater availability of 50% CC bean plants did not show sufficient growth for evaluation of gas exchange variables. With 80% CC in sandy soil, the plants had an average reduction of 75% in photosynthetic rate, 44% in stomatal conductance, and 45% in transpiration, regardless of the dose of clomazone applied, to plants grown under 100% CC (Fig. 3). Treatments with 80 and 100% CC and different doses of herbicide did not alter the internal concentration of CO_2. Still, the carboxylation efficiency (A/Ci) was reduced under conditions of 80% CC due to the more severe effects on the photosynthetic rate (Fig. 3).

In clayey soil, plants are grown at 50, and 80% CC showed a reduction of around 40% in A, 66% in gS, and 70% in E, with maintenance or increase in Ci, regardless of the dose of clomazone (Fig. 3).Plants under water deficit and herbicide stress can adopt several strategies to get rid of toxic effects, such as reduction in leaf area, plant elongation and growth (Kooyers, 2015), change in shoot/root ratio (Ahmadi et al., 2018), leaf drop and curling, leaf angle change and cuticle thickening (Ghanbari et al., 2013b). In addition to several physiological changes such as increases in abscisic acid (ABA) (Wilkinson et al., 2012), osmotic adjustment, reduction in the rate of photosynthesis, transpiration, and stomatal conductance (Pinheiro; Chaves, 2011).

Especially in soil with low water retention, such as sandy soil, stress occurs severely, causing rapid stomatal closure to prevent water loss by the plant (Brodribb et al., 2003; Ferrari et al., 2015; Da Cunha Valença et al., 2020). Rastgordani et al. (2023) and Varanasi, Prasad, and Jugulam (2016) point out that environmental conditions before, during, and after herbicide applications are responsible for influencing

the behavior of products, with adverse environmental conditions being the principal cause of molecule inconsistency, this information are similar to the results found in this work.

The roots are the first organ to notice the reduction in water availability. Under these conditions, the roots increase the release of abscisic acid from the root tissues to the xylem vessels and, consequently, to the guard cells to promote stomatal closure and limit water loss through transpiration (Sauter; Davies; Hartung, 2001). The reduction in stomatal conductance can limit the photosynthetic rate and allow the characterization of plants sensitive to water deficit ordinarily associated with lower tissue water potential and leaf area (Damatta et al., 2003). For intolerant plants, stomatal closure is an efficient strategy for short periods of drought when photosynthesis and crop productivity aren't affected (Costa França, 2000).

The lower photosynthetic rate associated with the maintenance of Ci indicates a biochemical limitation of photosynthesis since the CO_2 available in the substomatal chamber wasn't carboxylated. Photosynthesis and cell growth are primary processes influenced by drought. Excess energy in the thylakoids in the photosynthetic apparatus results in photoinhibition and reduced photochemical efficiency (Chaves et al., 2022). In addition, excess energy favors increased production of reactive oxygen species that can cause oxidation of membrane proteins and lipids (Xavier et al., 2018), degradation of the major subunit of ribulose-1,5-bisphosphate carboxylase oxygenase (RuBisCO) (Desimone et al., 1996), and deleterious effects on the Calvin Cycle, such as in the regeneration step of ribulose 1,5-bisphosphate (RuBP) (Müller et al., 2017).

Water restriction also compromised the growth of bean plants more intensely with the application of clomazone. At 7 DAE, there was a lower plant height (AP), mainly in those exposed to the highest dose of clomazone (378 g a.i. ha^{-1}) grown in clayey soil (data not shown). At 21 DAE, both the water availability factor and the dose of clomazone influenced the AP. AP was reduced by lower water availability in the soil (50% CC), regardless of the type of soil used and exposure to the herbicide (Fig. 4A). The highest AP decrease occurred with the combination of clayey soil, severe water restriction (50% CC), and the absence of the herbicide.

In field studies, Fernandes et al. (2011) reported that clomazone did not change the height of bean plants (Jalo Precoce cultivar) at 10 DAE, but it was significantly lower in reaction to the weeded control at 60 DAE.

As well as plant height, stem diameter, leaf area, and dry mass of bean plants were also more affected by water availability, showing lower values in the treatment with 50% CC, regardless of the dose of herbicide applied (Fig. 4B -D). In addition, leaf area and dry mass were lower in bean plants grown at 80% CC compared to 100% CC and even with lower values when grown in clayey soil to sandy soil (Fig. 4D). Water deficit has been reported to affect the growth, gas exchange, and production components of bean plants (Ghanbari et al., 2013a; Lanna et al., 2016; Galvão et al., 2019; Alves et al., 2021), including under application of some herbicides (De Sousa Linhares et al., 2014). The increase in the dose of clomazone

caused a reduction in the leaf area (under 80% CC) and in the dry mass of the bean plants to the lowest evaluated dose of the herbicide (126 g a.i. ha^{-1}) (Fig. 4).

Mesotrione, like clomazone, is also a carotenoid synthesis-inhibiting herbicide, which also caused a significant reduction in the dry mass of bean plants (Allemann; Molomo, 2016). The authors recommend a period of 270 days between product application and sowing to avoid damage to bean plants. On the other hand, clomazone at doses of 113 and 100 g a.i. ha^{-1} favored the highest stem diameter and dry mass of corn plants, respectively (Barbosa et al., 2017). Takano et al. (2012) also reported differential results between bean cultivars and the application of different doses of clomazone, demonstrating that tolerance to the herbicide depends on the genetic background of the cultivar. In this investigation, which considers the interaction between herbicide dose, soil type, and water availability, it was observed that the culture of bean plants in sandy soil with higher humidity brought fewer problems to the crop, regardless of the dose of clomazone applied.

Conclusion

The herbicide clomazone showed phytotoxicity lower than 60% 21 days after application at a dose of 378 g a.i. ha^{-1}, regardless of water availability for clayey and sandy soils.

The photosynthetic rate, stomatal conductance, and transpiration were reduced mainly as a function of water availability, regardless of the dose of clomazone applied to the sandy soil. In clayey soil, there was a biochemical limitation of photosynthesis in water conditions of 50 and 80% CC, with reduced carboxylation efficiency.

The emergence and growth of bean plants were favored under conditions of 100% CC in sandy soil. Severe water deficit (50% CC) compromised bean plant growth, regardless of clomazone application and soil type.

Water restriction associated with higher doses of clomazone compromised leaf area, dry mass, plant height, and stem diameter.

Declarations

Author's contribution

Conceptual idea: Trezzi, MM.; Brandler, D.; Galon, L.; Methodological design: Trezzi, MM.; Brandler, D.; Galon, L.; Data collection: Brandler, D.; Galon, L. ; Hartmann, KCD; Tonin, RJ; Data analysis and interpretation: Brandler, D.; Galon, L.; Hartmann, KCD.;Trezzi, MM.; Muller, C. Perin, GP. and Writing and editing: Brandler, D.; Galon, L.; Hartmann, KCD.;Trezzi, MM.; Tonin, RJ; Muller, C. Perin, GP.

Data availability statement:

The data presented in this study are available from the corresponding author upon reasonable request (D. Brandler).

Conflict of interest:

Brandler, D.; Galon, L.; Hartmann, KCD.;Trezzi, MM.; Tonin, RJ; Muller, C. Perin, GP. declare that they have no competing interests.

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Figures

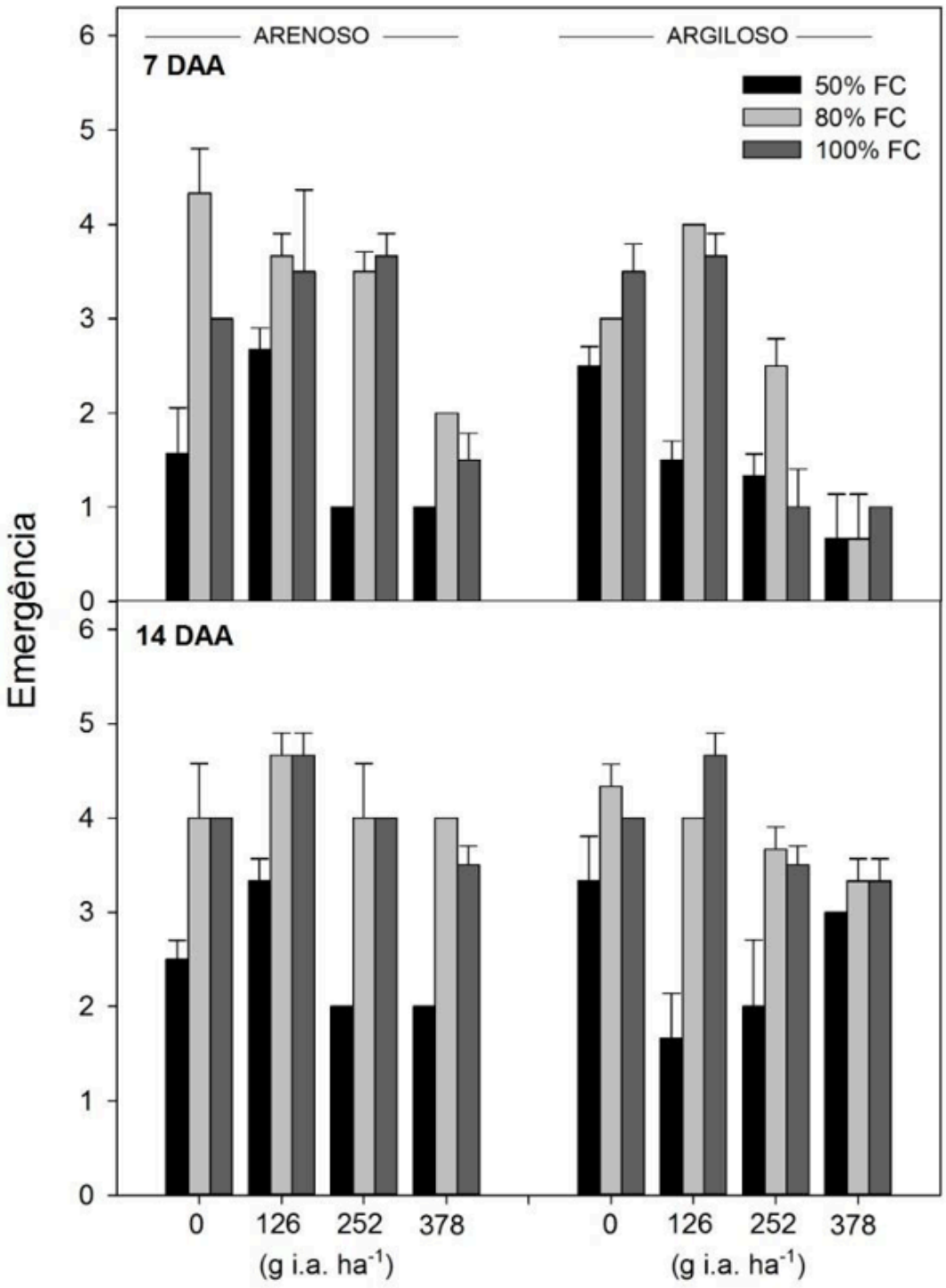


Figure 1

Plant emergence at 7 (A) and 14 (B) days after sowing (DAA) of doses of clomazone (0, 126, 252, 378 g i.a. ha-1), applied in pre-emergence of plants of beans, cultivar IAC Milênio, under moisture contents (5, 80 and 100% of field capacity), in sandy soil and clayey soil. Harvest 2019, UFFS, Erechim/RS. Bars represent mean ± SE (n = 4). Averages followed by a capital letter compare herbicide doses in different soils for each moisture content by Tukey's test ($p < 0.05$) and averages followed by lowercase letters

compare the moisture content imposed for each herbicide dose by Tukey's test ($p < 0.05$), and asterisk (*) indicates the difference between soils within each moisture content and herbicide dose ($p < 0.05$).

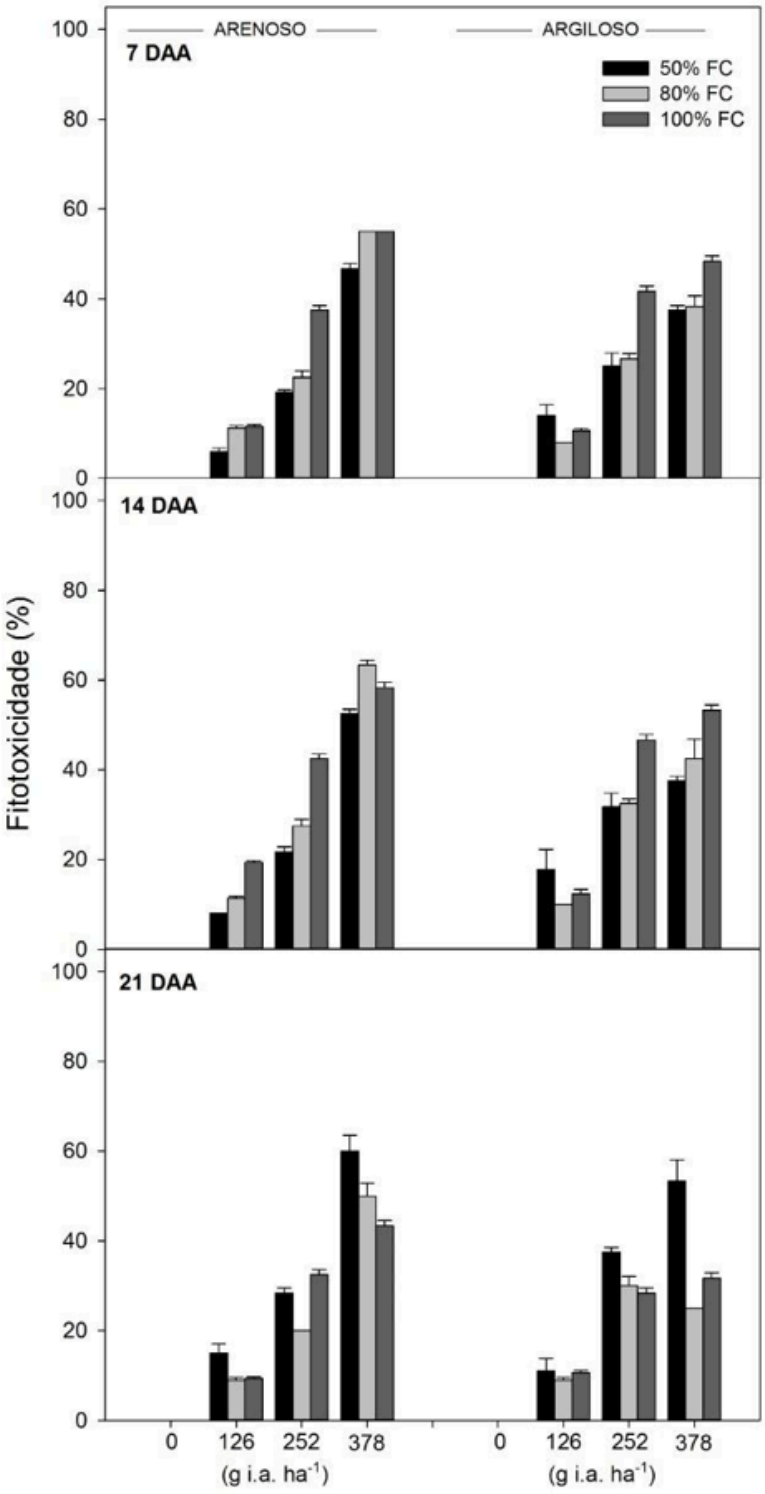


Figure 2

Phytotoxicity at 7 (A), 14 (B), and 21 (C) days after sowing (DAA) of clomazone doses (0, 126, 252, 378 g i.a. ha-1), applied in pre-emergence of common bean plants, cultivar IAC Milênio, under moisture contents (5, 80 and 100% of field capacity), in sandy soil and clayey soil. Harvest 2019, UFFS,

Erechim/RS. Bars represent mean ± SE (n = 4). Averages followed by a capital letter compare herbicide doses in different soils for each moisture content by Tukey's test ($p < 0.05$), and the standards followed by lowercase letters compare the moisture content imposed for each herbicide dose by Tukey's test ($p < 0.05$), an asterisk (*) indicates the difference between soils within each moisture content and herbicide dose ($p < 0.05$).

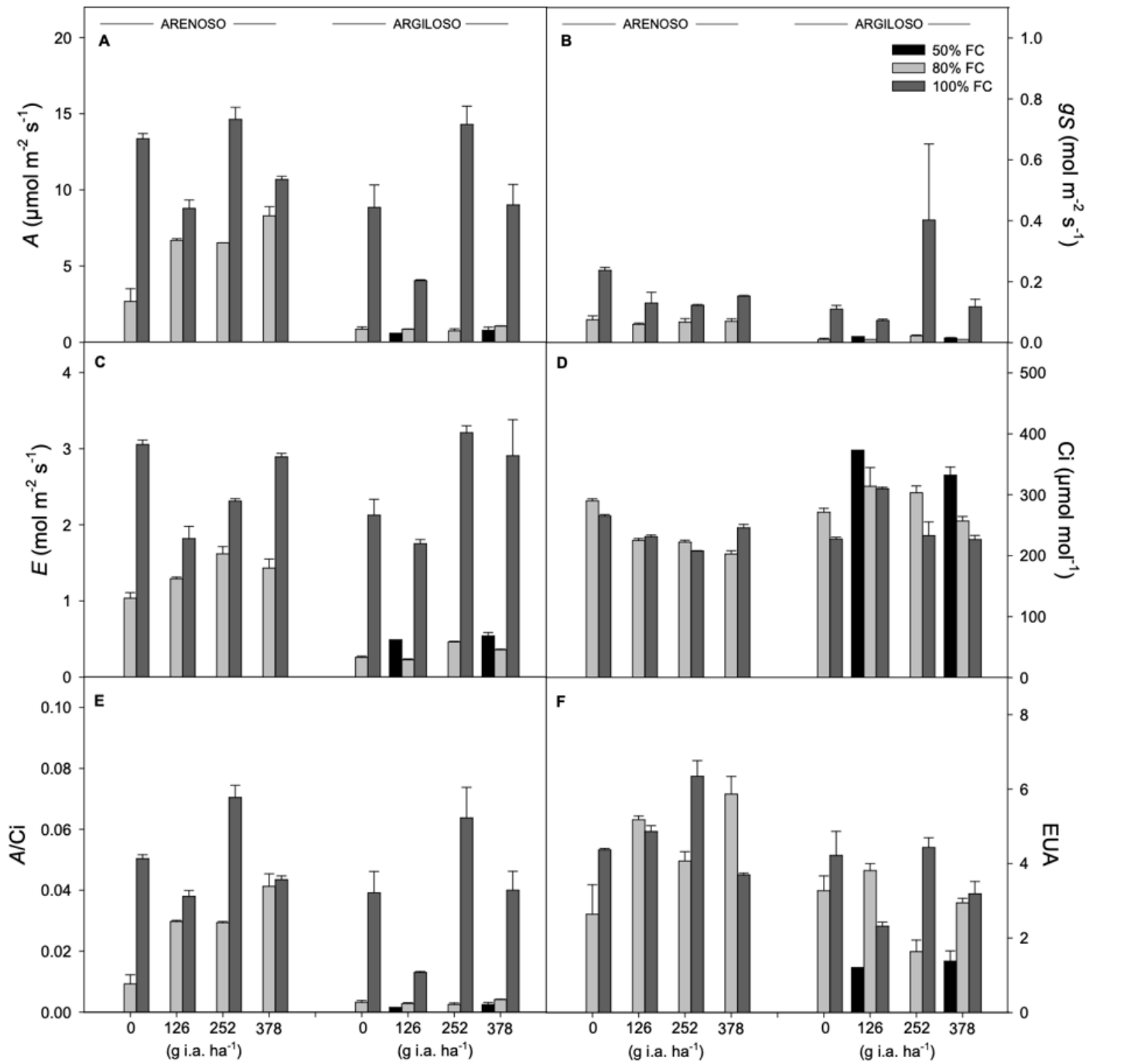


Figure 3

Photosynthetic rate (A) (A), stomatal conductance (gS) (B), transpiration (E) (C), internal CO2 concentration (Ci) (D), carboxylation efficiency (EC) (E) and water use efficiency (EUA) (F) 21 days after sowing (DAA) of doses of clomazone (0, 126, 252, 378 g i.a. ha-1), applied in pre-emergence of bean

plants, cultivar IAC Millennium, under moisture contents (5, 80 and 100% of field capacity), in sandy soil and clayey soil. Harvest 2019, UFFS, Erechim/RS. Bars represent mean ± SE (n = 4). Averages followed by a capital letter compare herbicide doses in different soils for each moisture content by Tukey's test ($p < 0.05$), the standards followed by lowercase letters compare the moisture content imposed for each herbicide dose by Tukey's test ($p < 0.05$), an asterisk (*) indicates a difference between soils within each moisture content and herbicide dose ($p < 0.05$).

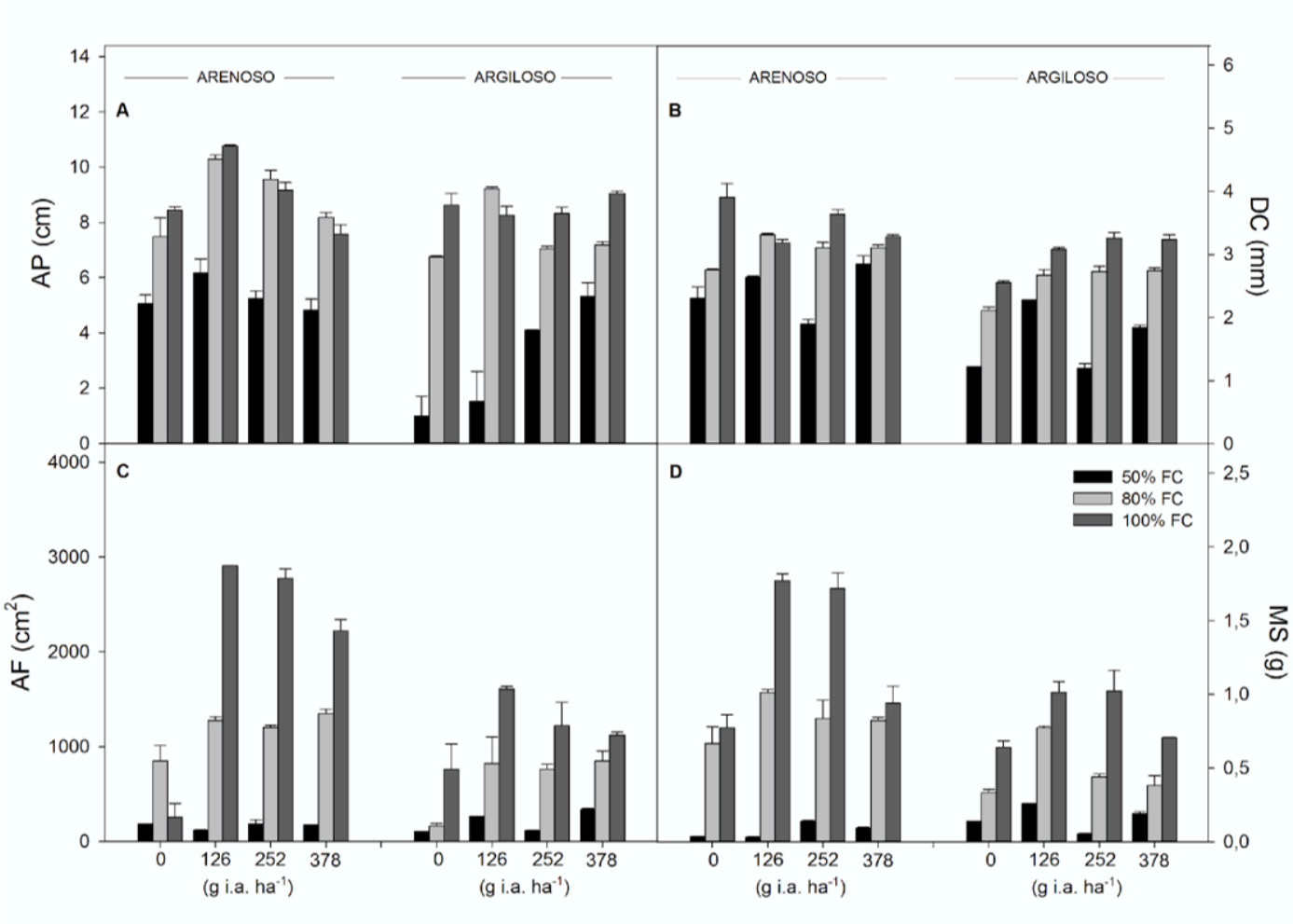


Figure 4

Plant height (AP) (A), stem diameter (DC) (B), leaf area (AF) (C), and shoot dry mass (MS) (D) 21 days after sowing (DAA) of clomazone doses (0, 126, 252, 378 g ai ha-1), applied in pre-emergence of bean plants, cultivar IAC Milênio, under moisture contents (5, 80 and 100% of field capacity), in sandy soil and clayey soil. Harvest 2019, UFFS, Erechim/RS. Bars represent mean ± SE (n = 4). Averages followed by a capital letter compare herbicide doses in different soils for each moisture content by Tukey's test ($p < 0.05$); standards followed by lowercase letters compare the moisture content imposed for each herbicide dose by Tukey's test ($p < 0.05$); and asterisk (*) indicates the difference between soils within each moisture content and herbicide dose ($p < 0.05$).