Australian Journal of
Crop Science
AJCS
AJCS 9(12):1249-1256 (2015) ISSN:1835-2707

Effect of drought stress on periods prior of weed interference (PPWI) in bean crop using arbitrary and tolerance estimation

Mariana C. Parreira[1], Arthur A.M. Barroso[2], João M. Portugal[3], Pedro L.da C.A. Alves[2]*

[1]College of Agronomy, Pará Federal University, Cametá, PA, CEP 68400-400, Brazil
[2]Department of Applied Biology, São Paulo State University, Jaboticabal, SP, CEP 14844-900, Brazil
[3]Department of Biosciences, Instituto Politécnico de Beja, Beja, Portugal

***Corresponding author: plalves@fcav.unesp.br**

Abstract

Weeds cause big losses in the crops yields. Drought combined with high temperatures can influence and enhance this effect. The present study was designed to determine the periods prior of weed interference on bean crops subjected to conditions of hydric comfort and drought, using two distinct approaches: arbitrary level of 5% productivity loss and tolerance level. The experimental treatments consisted of five coexistence periods of the crop and weeds: 0-15, 0-30, 0-45, 0-60, 0-harvest days after emergence and a control plot that was kept weed-free throughout the study period. The experimental design was a random block design with four replications. The periods prior of weed interference were consisted of 9 and 10 days of coexistence at the arbitrary 5% productivity loss and four and nine days at tolerance level for the conditions of hydric comfort and drought, respectively. *Beta maritima* was the major weed interfering in bean. Drought stress reduced the bean productivity up to 63%, where weeds reduced it by 65%. The tolerance level was more sensitive to abiotic stress influence in weed-crop interference.

Keywords: Competition, hydric stress, modelling, tolerance level, *Phaseolus vulgaris*.
Abbreviations: DAE_days after emergence; PPWI_period prior to weed interference; RI_relative importance; TL_tolerance level.

Introduction

The common bean (*Phaseolus vulgaris* L.) is a rich source of nutrients and is an excellent source of vitamins and minerals (Kutoš et al., 2013). The mean yield of bean plants can exceed 3,400 kg ha^{-1}, which by far exceeds the mean values obtained in countries such as Brazil and India (CONAB, 2014; Stone, 2008). This yield achieved at optimal condition with no abiotic and biotic factors. Among the biotic factors, weed interference is an important one, which causes losses that can reach up to 80% in bean plants (Barroso et al., 2010; Teixeira et al., 2009). Weed growth may influence the bean development due to a stronger competition, with fundamental factors as soil fertility and water availability (Crusciol et al, 2001).

Water availability is among the abiotic factors affecting bean plant yield. It is the most limiting factor to plant development, as only 3% of the absorbed water is used by plant (Taiz and Zeiger, 2013). The worldwide climate change directly affects the physiology of crops and weeds (Sage and Kubien, 2003). Drought, combined with high temperatures, reduces crop final yield (Lobell et al., 2013). Water sufficiency is particularly critical during early stages of bean development because the crop rapidly develops within the first few days of emergence, ensuring an advantage against weeds, which generally have higher water absorption capacity than bean plants (Procópio et al., 2004a).

In the recent years, numerous studies have been conducted on yield losses, in most cases stipulated at 5% (an arbitrary level), to calculate weed interference periods rather than economic criteria. The tolerance level (TL) proposed by Amaro and Baggioloni (1982), reflects the extent to which crops tolerate the presence of crop enemies. Portugal and Moreira (2011) applied this TL concept to identify when it is economically advantageous to control weeds.

Defining a period prior to weed interference (PPWI), calculated using economic criteria (TL), would be more advantageous for producers than arbitrarily stipulating an acceptable level of yield loss. The calculation of interference periods based on economic criteria and on crop water use is in agreement with the proposal of government agencies. According to the Intergovernmental Panel on Climate Change (IPCC), crop production will decrease due to high temperatures and periods of water stress in projections conducted up to 2030 (IPCC, 2014). As weed management is essential for higher crop yields, the objective of this study was to determine the period prior of weed interference of bean crop with and without drought stress via two approaches: 5% level of acceptable yield loss and tolerance level (TL).

Results and Discussion

Weed community

The weed community present at the site was similar for the two water conditions, consisting of 23 weed species (86% eudicotyledons, 13% monocots). The following eudicotyledon families had the largest numbers of species: Asteraceae (*Calendula arvensis* (L.), *Sonchus oleraceus* (L.), *Cichorium intybus* (L.), *Picris echioides* (L.), *Centaurea melitensis* (L.), *Silybum marianum* (L.) Gaertn, and *Xanthium spinosum* (L.)), Amaranthaceae (*Chenopodium album* (L.)

Table 1. Chemical analysis of the soil from the experimental site.

Parameters	Classification
Fine soil (%)	74.10
Bulk density	1.20
Manual or field texture	Fine
Total organic matter (%) (Walkeley and Black)	6 (very low level)
Extractable potassium mg k^{-1} (Egner-Riehn)	> 200 (very high level)
Extractable phosphorus mg k^{-1} (Egner-Riehn)	103 (high level)
pH (H_20)	7.1 (neutral reaction)

Source: Soil Analysis Laboratory, Biosciences Department, Beja School of Agriculture (Escola Superior Agrária de Beja - ESAB)

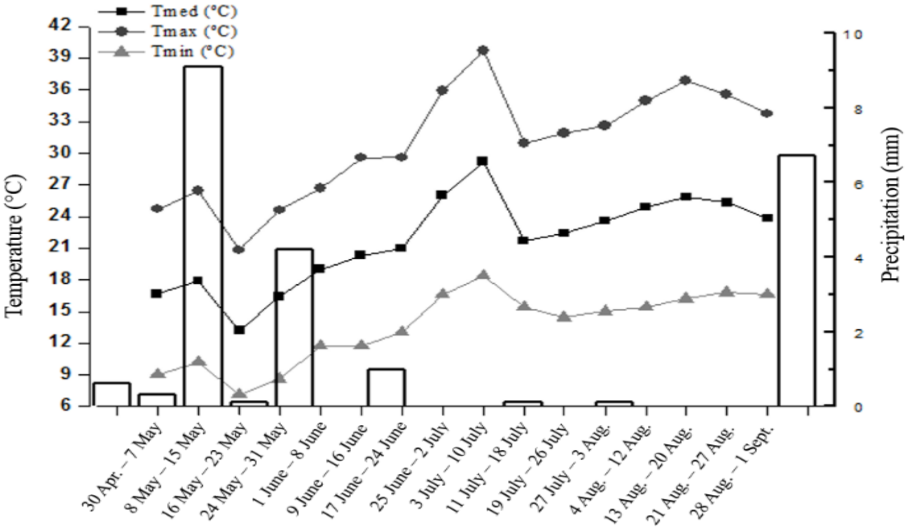

Fig 1. Temperature (minimum, maximum, and mean), relative humidity, and rainfall during the experimental period (2013).

var. *album* and *Chenopodium opulifolium* (Schrad), and Polygonaceae (*Polygonum aviculare* (L.) and *Rumex pulcher* (L.) subsp. *pulcher*). The families Boraginaceae (*Heliotropium europaeum* (L.)), Chenopodiaceae (*Beta maritime* (L.)), Convulvulaceae (*Convolvulus arvensis* (L.) subsp. *arvensis*), Cucurbitaceae (*Ecballium elaterium* (Batt.) Costich subs. *dioicum*), Fabaceae (*Medicago polymorpha* (L.)), Malvaceae (*Lavatera cretica* (L.)), Plantaginaceae (*Kickxia spuria* (L.) Dumort.), and Portulacaceae (*Portulaca oleracea* (L.)) were also present. Among the monocots, only family Poaceae was present, with three species (*Phalaris minor* (Retz.), *Lolium multiflorum* (Lam.), and *Phalaris brachystachys* (Link.)).

Under the beneficial water conditions, *B. maritima, C. album,* and *C. arvensis* exhibited the highest relative importance (RI) values throughout the entire experimental period. *Beta maritima* exhibited the highest RI at 15 days after emergency (DAE, >46%) (Fig 2), but at 30 DAE, this value decreased (to 30%) mainly due to a decrease in the number of individuals found at the site, which decreased from 53 to 26 (Fig 3). Throughout the experimental period, the RI of this specie was relatively constant, without large fluctuations, resulting in a mean value of 40%, largely due to its high fresh biomass per square meter, which remained close to 100 grams (Fig 4). This observation indicates that the species that survived at the site developed faster than the others, accumulating large amounts of biomass over a short period of time.

Chenopodium album and *C. arvensis* exhibited a similar pattern throughout the entire experimental period, not exceeding 10% RI, except for *C. album* at harvest, when the RI was 17%. The pattern observed is a result of the plants having high biomass (>130 g m^{-2}, Fig 4), even at low densities (7 plants m^{-2}, Fig 3), which increased their RI at the time of evaluation (Fig 2).

In the weed community of the bean plants subjected to water deficiency, *B. maritima* and *P. aviculare* exhibited the highest RI values. *Beta maritima* again exhibited the highest RI throughout the experiment, which ranged from 30 to 41% (Fig 2). At 15 DAE, *B. maritima* exhibited the lowest RI (30%) value, which was similar to the RI recorded under beneficial water conditions, explained by the low density of individuals and, in this case, low biomass (Fig 3 and 4). After this period, the RI value increased to 41% and remained stable until the harvest.

The RI of *P. aviculare* was stable until 30 DAE (Fig 2), at approximately 7%, but this importance decreased to 3% at 45 DAE. However, in the following evaluation, there was a higher density of *P. aviculare* individuals with large amounts of fresh biomass (175 grams m^{-2}), increasing the RI to 21%. At harvest, the fresh weight was much lower (50 grams m^{-2}), decreasing the RI (11%) (Fig 2). This pattern only occurred under water stress conditions because *P. aviculare* tolerates this condition well (Parker, 1972). Under beneficial water conditions, *P. aviculare* was suppressed by the development of the other plants and did not occupy a prominent position in the community because of its low competitive potential (Uva et al., 1992). The pattern observed for *C. album* was normal, without fluctuations throughout the entire experimental period and with an approximate RI of 10%.

The increased number of *B. maritima* individuals 15 DAE under both of the water conditions may be related to the environmental conditions. This evaluated period coincides with local rainfall, which may have caused a second wave of seed germination, as occurred within the irrigated area. The lack of a significant water-stress period during early crop

Table 2. Parameters determined for the Boltzman sigmoidal equations fitted to bean yield data as a function of the weed intercropping periods for plants under sufficient water and water-deficit conditions.

Parameters	Water conditions	
	Beneficial	Stress
P1	2,721.00	998.00
P2	952.00	233.00
X_0	26.94	19.47
dx	8.34	3.33
R^2	0.98	0.99
Production decrease	65%	76%

Legend: y (bean yield of bean plants as a function of coexistence periods), P1 (maximum production obtained in plants weeded throughout the cycle), P2 (minimum production obtained in plants intercropped with weeds during the maximum duration of 97 days), X (upper limit of the coexistence period), X_0 (upper limit of the coexistence period that corresponds to the intermediate value between maximum and minimum production), dx (parameter that indicates the speed of production loss as a function of coexistence period), and R^2 (regression coefficient).

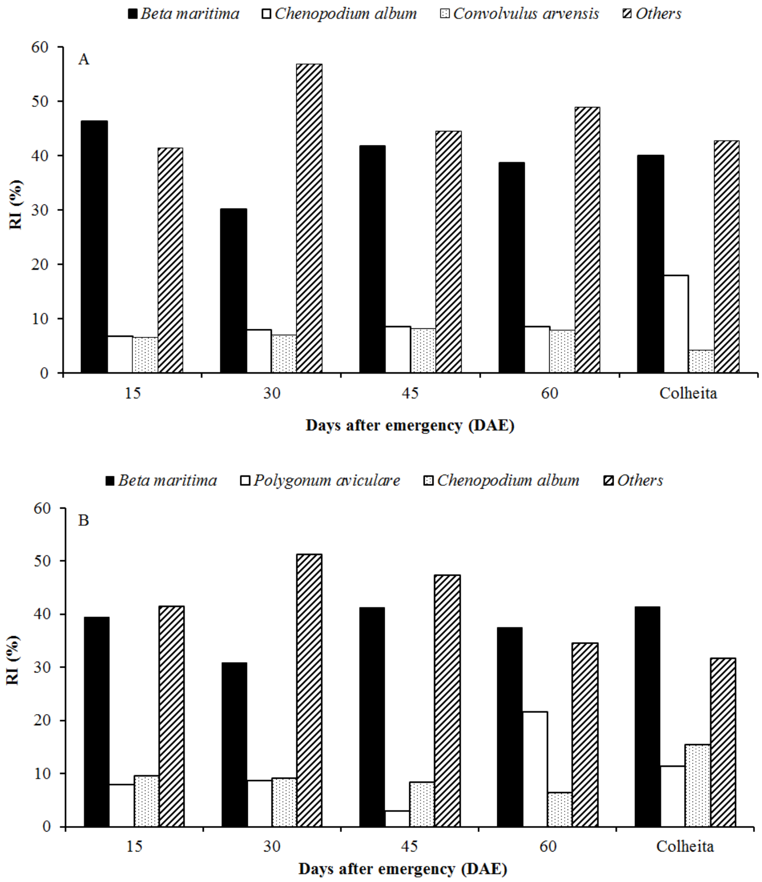

Fig 2. Relative importance (%) of the main weeds *Beta maritima*, *Chenopodium album*, *Convolvulus arvensis*, and *Polygonum aviculare* and of the other plants comprising the weed community at the end of the coexistence periods for the bean plants under sufficient water (A) and water stress conditions (B).

development may have also contributed to the rapid *B. maritima* development compared to the other plants. This observation has been corroborated by other researches, related to the fact that bean plants have slow early development (Cobucci et al., 1996).

According to Molina et al. (2014), there is a positive correlation between *B. maritima* development and rainfall levels. Additionally, according to Fayed et al. (1999), the species has high competitive potential, absorbing large amounts of nitrogen and potassium. In addition to these factors, *B. maritima* may have indirectly interfered with the other plants by its allelophatic potential, a plant rich in phenolics and flavonoids (Morales et al., 2012; Sánchez-Mata et al., 2012). It is noteworthy that in the studied weed community, the initial rainfall made the selection for individuals less pronounced, which corroborates the high relative importance observed for other species (Fig 2).

Bean yield and quality

The bean plant yield without weed interference (P1) under sufficient water conditions was estimated at 2,721 kg ha^{-1} (Table 2), whereas under water stress, it was estimated at 998 kg ha^{-1}, which represents a 63% decrease in crop yield due to this abiotic factor. In contrast, when bean plants coexisted with the weed community throughout their entire cycle under sufficient water conditions (P2), the yield amount decreased to 952 kg ha^{-1}, which represents a 65% decrease due to this biotic factor.

Table 3. Periods prior of weed interference (PPWIs) calculated based on a 5% reduced bean yield and the tolerance level (TL) for sufficient water and water-stress conditions and the difference in number of days between the approaches.

	Days after emergence (DAE)	
Parameters	Beneficial water	Water stress
5%	9	10
TL	4	9
(5% - TL)	5	1

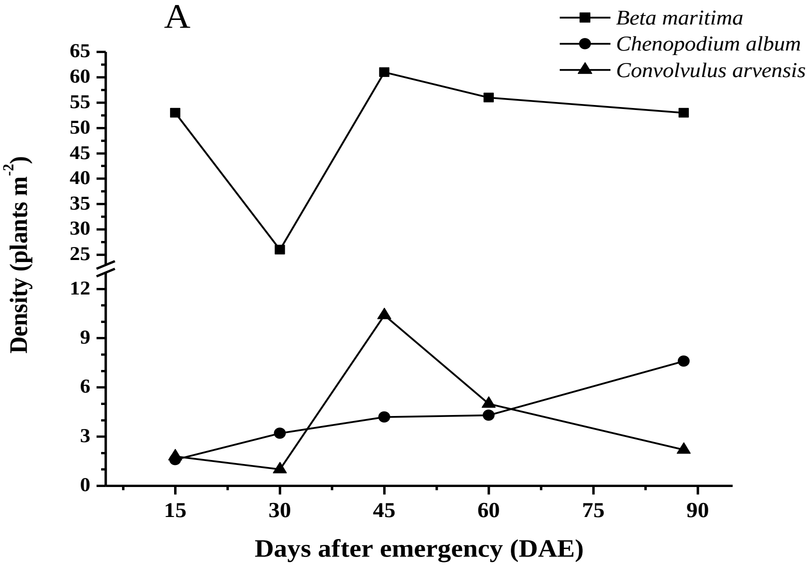

Fig 3. Density of the main weeds (plants m^{-2}) at the end of the coexistence periods with bean plants under sufficient water (A) and water-stress conditions (B).

With these data, it is possible to affirm that the biotic stress (weed interference) was severe as biotic stress (water deficiency) on bean plant yield. Additionally, the speed of decreasing crop yield (dx) due to the weed coexistence periods was 2.5 times lower under sufficient water conditions compared to the communities under water stress (Table 2). The maximum production of bean plants under sufficient water conditions decreased by half near the 26th day of weed coexistence, whereas this decrease occurred close to the 20th day under water-deficit conditions.

The reduced bean production corroborated with previous studies. In Italy, which has a climate similar to Portugal, weeds reduced twining bean production by 60% in 2006 (Stagnari and Pisante, 2011). In Brazil, bean crop yield was significantly reduced by the interference of weeds throughout the crop life cycle. In São Paulo state, Parreira et al. (2012) found 56% and 60% decreases in crops spaced 0.45 m and 0.60 m between rows, respectively. In the absence and presence of topdressing, Bressanin (2013) obtained 58% and 56% reduced production, respectively, when weeds were present throughout the bean plant cycle. In Iran, Yadavi et al. (2012) observed a 53% loss in yield caused by weeds. These findings show that the bean crop is greatly compromised by weeds worldwide. Water stress also affected bean plant yield because water availability affects plant growth. This process is linked to the interaction between stomatal opening and dry matter yield; stomatal closing, performed for the plant's water balance, directly affects crop production (Oliva et al., 1989). This effect was also observed by Stone and Moreira (2001) and Guimarães et al. (1996) in beans when water stress occurred during the vegetative phase, substantially reducing the bean-filling stage.

Water is a limiting factor for plant growth. On average, only 2% of water absorbed will become part of the organism and the rest is lost through transpiration. Water stress affects plant growth by reducing cellular expansion and stem and leaf growth (Taiz and Zeiger, 2013). Weeds that are more adapted to water-deficit conditions tend to continue their development even under adverse conditions, e.g., black-jack plants (*Bidens pilosa* L.) and wild poinsettia (*Euphorbia heterophylla* L.), which have higher water-use efficiency than bean plants (Procópio et al., 2004b). There were no differences in bean quality related to the moisture content, total ash, total fat, protein, fibres, and non-nitrogenous extracts from both of the tested water conditions.

Coexistence periods

With 5% arbitrary production loss, the PPWI was similar for the two water conditions, being 9 DAE for beneficial water conditions and ten DAE for water stress conditions (Fig 5). This pattern shows that the crop was extremely sensitive to competition with this weed community. The "Manata" bean cultivar exhibited a competitive disadvantage because it displayed type one growth habit and has an erect architecture, is small, and has few branches; therefore, the plant leaves space and light for weeds to quickly infest the area.

Stagnari and Pisante (2011), using the 5% arbitrary level of reduced yield, found PPWI similar to that of ten DAE for twining bean plants in Italy. In Brazil, also based on the 5% arbitrary level, PPWIs ranged from 7 to 20 DAE when the cultivar or planting season changed (Bressanin et al, 2013; Parreira et al, 2011, 2012).

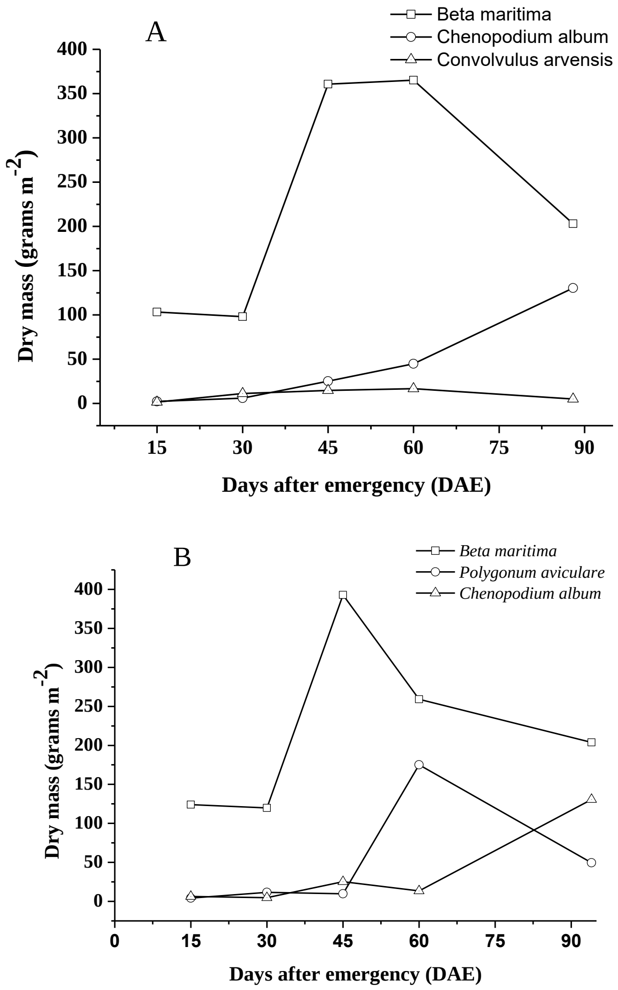

Fig 4. Fresh weight of the main weeds (g m^{-2}) at the end of the coexistence periods with bean plants under sufficient water (A) and water stress conditions (B).

Using the tolerance level (TL) particular to each case, there were approximatly 2% and 4% economically acceptable yield losses for the irrigated and water-deficit conditions, respectively. The PPWIs that found according to the TLs were four DAE and nine DAE under sufficient water and water-stress conditions, respectively (Fig 5). However, reduced production (in kilogram per hectare) was similar for the two conditions, 43.53 kg ha^{-1} and 42.91 kg ha^{-1} under beneficial water and water stress conditions, respectively.

At the 5% arbitrary level of yield loss, the reductions were 136 kg ha^{-1} and 86.1 kg ha^{-1} under sufficient water and water-stress conditions, respectively. If the price for beans is $ 3.15 (considering the study date) the producer would lose $ 427.80 and $ 270.83 under irrigation and water stress, respectively, adopting the 5% arbitrary level. With TL, the losses would decrease to $ 136.92 and $ 134.00, with a return of $ 290.88 under the beneficial water conditions and $ 135.86 for the crop subjected to water stress, exceeding the price of a new weed-control application ($ 110.38) under water stress and up to two applications under sufficient water conditions.

However, the difference in days was small from one approach to another, with the PPWI decreasing by five days and one day under the irrigation and water-stress conditions, respectively (Table 3). The PPWI that found using both of the approaches was short, during the early plant development, for the crops under both irrigation and water stress. However, regardless of the approach used to calculate the period prior of weed interference on the bean crop, weeds should be controlled. If chemical control is an option, an herbicide with pre-emergence action with a residual effect of at least ten days should be chosen.

It would be advantageous for producers to determine the PPWI according to economic criteria because the desirable economic return is obtained using these criteria, especially if the crop cultivated has a high technological level with high yield (beneficial water conditions). The use of economic indices was more sensitive to biotic and abiotic variation than the use of an arbitrary level of tolerance to interference, which corroborates with other studies (Parreira, 2012), including studies for other crops (Keller et al., 2014).

Materials and Methods

Sites description

Two experiments were conducted under field conditions in the municipality of Beja, located within the lower Alentejo region, Portugal (38°00’65” latitude, 07°51’55” longitude, and altitude of 288 m). The *P. vulgaris* cultivar "Manata" ("Fidalgo Anão") belonging to the red commercial group,

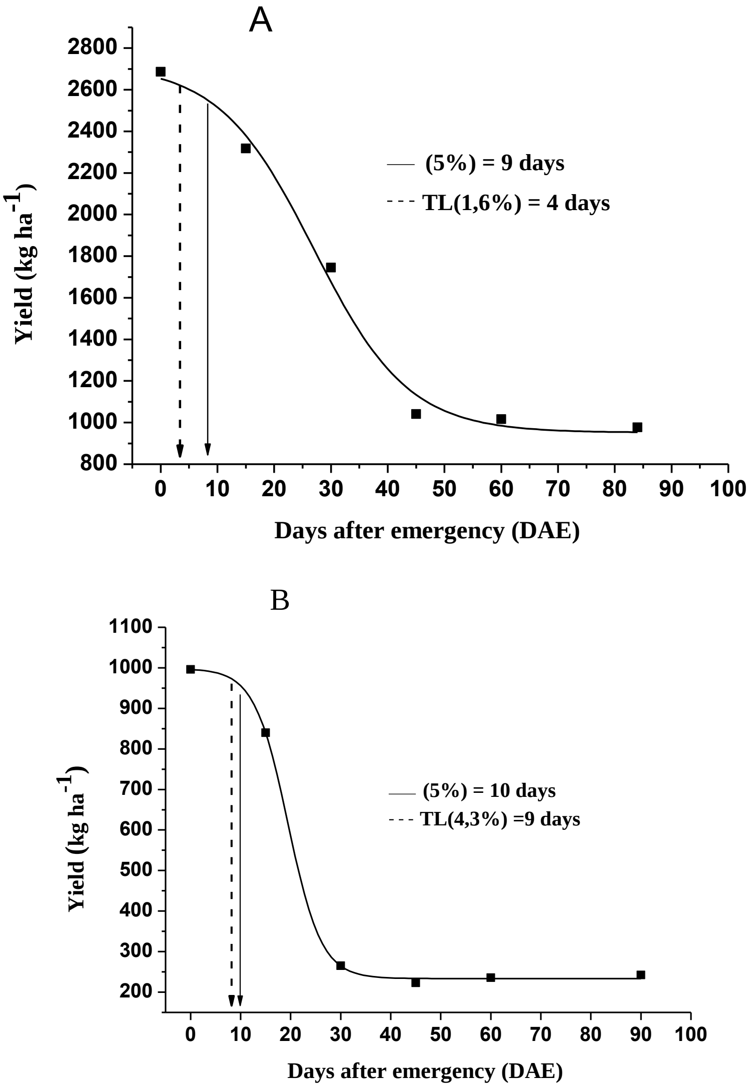

Fig 5. Crop yield in response to weed coexistence periods to define the period prior of weed interference considering a 5% arbitrary yield loss and tolerance level (TL) for bean plants under irrigation (A) and water stress (B).

with type one growth habit (erect shrubby plants), was used for the experiments. The soil of the experimental site was classified as black clays: slightly decarbonised calcareous soil of basaltic rocks or clayey calcareous or marl sandstones (Vertisols for USDA classification). The soil chemical analysis results are presented in Table 1. The soil was conventionally prepared.

The crop was conventionally sown in five rows, spaced 0.45 m apart, at a density of 15 seeds per meter, on 5 May 2013. Throughout the experimental period, preventative insecticides and fungicides were applied to the entire area to promote crop health. The experimental plots consisted of six 5-meter long planting rows, resulting in an area of 11.25 m^2. The two outside rows plus half a meter from each end of each experimental plot were considered borders and were discarded, resulting in a useful area of 5.4 m^2.

Treatments

The experimental treatments consisted of five different periods of co-existence between the bean plants and weeds: 0-15, 0-30, 0-45, 0-60, and 0-harvest days after emergence (DAE) and one control plot without coexistence with weeds. Through these periods, weeds were not controlled in the area. These coexistence periods were studied under two conditions: with and without water stress. For each water condition, a randomised block design was used with five replicates. The area without water stress (beneficial water conditions) was drip irrigated every 30 cm in rows alternating between crop inter-rows. The area was irrigated whenever necessary and was monitored using the Diviner® system, which measures field capacity via soil sensors. The area with water stress was not artificially irrigated. Rainfall, relative humidity, and minimum, maximum, and mean temperature data at the experimental site throughout the experimental period are shown in Fig 1.

Evaluations

The weed community present within the areas at the end of each coexistence period in each plot was evaluated. The weeds present in two sampling areas (0.25 m^2) were randomly removed, identified, separated by species, counted, and weighed to obtain the dry biomass. After the end of their respective coexistence periods, the experimental plots were kept without weeds until harvest through periodic weeding.

From the weed community data, the relative importance of each weed species was calculated, using an index involving three factors: relative frequency, relative density, and relative dominance, calculated according to formulas proposed by Mueller-Dombois and Ellemberg (1974).

Harvest was different for the two water conditions according to natural pod opening; harvest began at 84 DAE and 90 DAE for the plants under water deficit and beneficial water conditions, respectively. Both of the harvests were performed manually. The pods were mechanically threshed, and the harvested beans were weighed.

Statistical analysis

Yield data analysis was performed individually for each water condition, and the results were subjected to regression analysis using the Boltzmann sigmoidal model (Equation 1) in the program Origin8® (ORIGINLAB Corporation USA).

$$y = \frac{(P1 - P2)}{1 + e^{(X - X_0)/dx}} + P2 \qquad [1]$$

where,

y = bean yield as a function of the coexistence period;

P1 = maximum production obtained from weeded plants during the entire cycle;

P2 = minimum production obtained from plants coexisting with weeds during the maximum period (harvest);

(P1 – P2) = production losses;

X = upper limit of the coexistence period;

X_0 = upper limit of the coexistence period that corresponded to the intermediate value between maximum and minimum production; and

dx = parameter that indicates the speed of production loss as a function of the coexistence period.

Based on the regression equations, the periods prior of weed interference were determined for the arbitrary tolerance level of 5% reduced bean plant yield (compared to the treatment with the absence of weeds) and for the tolerance level (TL), which was calculated according to Portugal and Moreira (2011), formula 2.

$$Y^* = \frac{C}{P.\ Ypp.\ E} \text{x}\ 100 \qquad [2]$$

Where,

Y* = percentage of losses;

C = price of weed control: herbicide plus herbicide application cost (fixed costs such as depreciation of the tractor and sprayer and variable costs such as labour, lubricant, and fuel);

P = price per kilo of beans paid to the producer;

Ypp = potential production paid to the producer, and

E = herbicide safety factor

Crop year values from 2013 provided by the Agrarian University of Beja (Escola Superior Agraria de Beja - ESAB) were used to parameterise the model. Three herbicides were considered when calculating the cost of weed control: pendimethalin (3,4-Dimethyl-2,6-dinitro-N-pentan-3-yl-aniline, applied pre-emergence) at a cost of \$ 28,60, quizalofop-P-ethyl (R-2-[4-(6-chloroquinoxalin-2-yloxy) phenoxy] propionic acid), applied post-emergence) to control monocots at a cost of \$ 61,77, and glyphosate (N-(phosphonomethyl)-glycine, applied post-emergence) locally applied to difficult-to-control plants at a cost of \$ 2.86. The cost of herbicide application per hectare (fixed and variable costs) was \$ 17.16. Thus, weed control per hectare was set at \$ 110.38.

Crop yield (potential production) was obtained in each particular case based on the control, which was free from weed interference during the entire experimental period. The monetary value of beans was obtained by consulting bean producers from Alentejo and was set at 3.15 dollars kg^{-1}. The herbicide safety factor used was 0.8. After harvest, the beans were subjected to technological analyses to calculate moisture content, total ash, and totals for fat, protein, fibres, and non-nitrogenous extracts for beans from both of the tested water conditions.

Conclusions

The periods prior of weed interference were nine and ten days of coexistence at the arbitrary 5% productivity loss and four and nine days at tolerance level for the conditions of hydric comfort and stress, respectively. The tolerance level is more sensitive to abiotic stress influence in weed-crop interference relations. Weed competition did not affect bean quality. Water and weed stress caused a similar bean yield loss.

Acknowledgments

To CAPES (Coordination for the Improvement of Higher Education Personnel), To CNPq (National Council for Scientific and Technological Development) and FAPESP (São Paulo Research Foundation).

References

Amaro PM, Baggioloni M (1982) Introduction to integrated pest management. FAO/DGPPA, Lisboa.

Barroso AAM, Yamauti MS, Alves PLCA (2010) Interference between weed species and two bean cultivars in two sowing season. Bragantia. 69:609-616.

Bressanin FN, Nepomuceno MP, Martins JVF, Carvalho LB, Alves PLCA (2013) Period of weed interference in bean with nitrogen fertilizer. Rev Ceres. 60:43–52.

Cobucci T, Ferreira FA, Silva AA (1996) Weed control. In: Araujo RS, Rava CA, Stone LF (ed) Common bean crop in Brazil. Potafos, Piracicaba.

CONAB (2014) Companhia Nacional de Abstecimento: Indicadores da Agropecuária. Brasilia. Available at: http://www.conab.gov.br (Acessed 10 Nov. 2014).

Crusciol CAC, O ARF, Zucareli C, Sá ME, Nakagawa J (2001) Produção e qualidade fisiológica de sementes de arroz de terras altas em função da disponibilidade hídrica. Rev Bras de Sementes. 23:287-293.

Fayed MTB, El-Geddawy IH, Zeny MM (1999) Influence of weed interference on growth, yield and quality of sugar beet. Egyp J Agric Res. 77:1239-1249.

Guimarães CM, Brunini O, Stone LF (1996) Adaptation of common bean (*Phaseolus vulgaris* L.) to drought (i. root density and root efficiency). Pesq Agrop Bras. 31:393-399.

IPCC (2014) Intergovernmental panel of climate change. Climate change 2014: central and South America. http://ipccg2.gov/ar5/images/uploads/wgiiar5-chap27_fgdall.pdf (Accessed 12 Oct. 2014).

Keller M, Bohringer N, Mohring J, Rueda-Ayala V, Gutjahr C, Gerhards R (2014) Long-term changes in weed occurrence, yield and use of herbicides in maize in South-Western Germany, with implications for the determination of economic thresholds. Weed Res. 54:457–466.

Kutos T, Golob T, Kac M, Plestenjak A (2003) Dietary fibre content of dry and processed beans. Food Chem. 80:231–235.

Lobell DB, Baldos ULC, Hertel TW (2013) Climate adaptation as mitigation: the case of agricultural investments. Environ Res Lett. 8:1-12.

Molina M, Tardío J, Aceituno-Mata L, Morales R, Reyes-García V, Pardo-de-Santayana M (2014) Weeds and food diversity: natural yield assessment and future alternatives for traditionally consumed wild vegetables. J Ethnobiol. 34:44–67.

Morales P, Carvalho AM, Sánchez-Mata MC, Cámara M, Molina M, Ferreira ICFR (2012) Tocopherol composition and antioxidant activity of Spanish wild vegetables. Genet. Resour. Crop Evol. 59:851–863.

Mueller-Dombois D, Ellembergh H (1974) Aims and methods of vegetation ecology. John wiley and sons, New York.

Oliva MA, Barros NF, Souza-Gomes MM, Lopes NF (1989) Drought indicators in *Eucalyptus camaldulensis* dehn. regarding water stress and mineral nutrition. Rev Árvore 13:19-33.

Parker KF **(**1972) An illustrated guide to Arizona weeds. The University of Arizona press, Tucson, AZ.

Parreira MC, Alves PLCA, Peñaherrera-Colina LA (2011) Weeds influence in commom bean as a function of spacing and plant density. Planta Daninha. 29:761–769.

Parreira MC, Barroso AAM, Pereira FCM, Alves PLCA (2012) Modeling of weeds interference periods in bean. Planta Daninha. 30:713–720.

Portugal JM, Moreira I (2011) Evaluation of economic levels for the *Solanum americanum* x tomato crop interaction using multiple models. Planta Daninha. 29:751–760.

Procópio SO, Santos JB, Silva AA, Donagemma GK, Mendonça ES (2004a) Permanent wilting point of soybean, bean, and weeds. Planta Daninha. 22:35-41.

Procópio SO, Santos, JB, Silva AA, Martinez CA, Werlang RC (2004b) Physiological characteristics of soybean and commom bean crops and three weed species. Planta Daninha. 22:211–216.

Sage RF, Kubiens DS (2003) Quo vadis c(4)? An ecophysiological perspective on global change and the future of c(4) plants. Photosynth Res. 77**:**.209–225.

Sánchez-Mata MC, Cabrera Loera RD, Morales P, Fernández-Ruiz, Cámara M, Díez-Marqués C, Pardo-de-Santayana M, Tardío J (2012) Wild vegetables of the Mediterranean area as valuable sources of bioactive compounds. Genet Resour Crop Evol. 59:431–443.

Stagnari F, Pisante M (2011) The critical period for weed competition in French bean (*Phaseolus vulgaris* L.) in Mediterranean areas. Crop Prot. 30:179-184.

Stone LF, Moreira JAA (2011) Commom bean response to nitrogen topdressing under different irrigation levels and soil tillages. Pesq Agropec Bras. 36:473–481.

Taiz L, Zeiger E (2013) Plant physiology. 5 ed. Artmed, Porto Alegre, Brazil.

Teixeira IR, Silva RP, Silva AG, Freitas (2009) Competition between the commom bean and weed in function of cultivar growth type. Planta Daninha. 27:235-240.

Uva RH, Neal JC, Ditomaso JM (1997) Weeds of the Northeast. Comstock publishing associates, Cornell University Press.

Yadavi A, Movahedi-Dehnavi, Kiani M (2012) Interaction effects of planting date and weed competition on yield and yield components of three white bean cultivars in semirom. J Crop Produc Proces. 2:29-30.