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CROP PROTECTION

Periods of weed interference in chickpea grown under different doses of nitrogen fertilizer topdressing

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ABSTRACT. Weed interference can reduce chickpea growth and, therefore, productivity depending on the period of coexistence and the nutritional status of the crop, among other factors. A study was performed over two crop years to estimate the critical period of weed interference (CPWI) during chickpea production under three doses of nitrogen (N) fertilizer topdressing (0, 50, and 75 kg N ha^{-1}). The experiments were conducted at 0, 7, 14, 21, 28, 35, 42, 56, 63, and 140 days after emergence (DAE) of chickpea/weed coexistence under two conditions: initially weed-free and initially weed-infested. The presence of weeds negatively affected chickpea production and reduced yields by 70% on average regardless of N rate, rendering the crop economically unfeasible. The CPWI ranged from 5 to 76 DAE and was not affected by N topdressing up to 75 kg N ha^{-1} in both crop years, assuming an acceptable production loss of 5%. Although the CPWI without fertilization (0 kg N ha^{-1}) was similar to that when fertilized with 50 and 75 kg N ha^{-1}, the two topdressing doses increased chickpea productivity by 37% and 51%, on average, respectively.

Keywords: *Cicer arietinum* L.; coexistence periods; critical period of interference; productivity.

Períodos de interferência das plantas daninhas na produtividade de grão-de-bico cultivado sob doses de adubação nitrogenada em cobertura

RESUMO. A interferência de plantas daninhas pode reduzir o crescimento e, portanto, a produtividade das plantas de grão-de-bico, dependendo do período de coexistência e do estado nutricional da planta, entre outros fatores. Para estimar o período crítico de interferência de plantas daninhas (PCPI) durante a produção de grão-de-bico cultivado sob três doses de cobertura de adubação nitrogenada (0, 50 e 75 kg N ha^{-1}), foi realizado um estudo em dois anos agrícolas. Os experimentos foram conduzidos os vários períodos de 0, 7, 14, 21, 28, 35, 42, 56, 63 e 140 dias após a emergência - DAE da coexistência de grão-de-bico/plantas daninhas em duas situações: inicialmente livre das plantas daninhas e inicialmente infestado por plantas daninhas. A presença de plantas daninhas afetou negativamente a produção de grão-de-bico e reduziu os rendimentos em 70%, em média, independentemente da taxa de N, tornando a cultura economicamente inviável. O PCPI não foi afetado pela adubação nitrogenada em cobertura até 75 kg N ha^{-1} em ambos os anos de cultivo, permanecendo de 5 a 76 DAE, considerando uma perda de produção de 5% como aceitável. Embora os PCPIs quando fertilizado com 50 e 75 kg N ha^{-1} permaneceram semelhantes ao período de interferência sem adubação (0 kg N ha^{-1}), a adubação nitrogenada aumentou a produtividade do grão-de-bico em 37% e 51%, em média, respectivamente.

Palavras-chave: *Cicer arietinum* L.; períodos de convivência, período crítico de interferência, produtividade.

Introduction

Chickpea (*Cicer arietinum* L.) is a very important crop that is mainly used for human and animal food (Mohammadi, Javanshir, Khooie, Mohammadi, & Salmasi, 2005; Hossain, Hasan, Sultana, & Bari, 2016), and it is the second most widely grown legume worldwide (Pang et al., 2017) after soybean (Varshney et al., 2014). This crop can be grown in many areas, including marginal land and low-fertility areas (Esfahani et al., 2014), and its cultivation plays a key role in maintaining soil fertility, especially in tropical regions (Varshney et al., 2009), thus representing an important component of crop rotation. Current global chickpea production is approximately 13 million tons (Mt) (FAO, 2014), with an expected increase to 17 Mt in 2020 (Abate et al., 2012).

Chickpea plays important roles in the human diet (Ulukan, Bayraktar, & Koçak, 2012) and agricultural systems (Varshney et al., 2014). The seeds are rich in fiber, vitamins, carbohydrates, mineral salts (Ulukan et al., 2012), unsaturated fatty acids and β-carotene (Gaur, Jukanti, & Varshney, 2012) and are a good source of protein, with a content of approximately 21% (Esfahani et al., 2014). Therefore, this crop plays a key role in the food security of developing countries and is an important component of subsistence agriculture (Varshney et al., 2014).

Weeds represent a great barrier to the productivity of several agricultural crops (Kaushik, Rai, Sirothia, Sharma, & Shukla, 2014), and similar to other crops, chickpea can be threatenedby both direct and indirect weed interference, which can quantitatively and qualitatively reduce production depending on the severity (Amaral, Pavan, Souza, Martins, & Alves, 2013; Amaral, Souza, Pavan, Gavassi, & Alves, 2015). Singh and Bajpai (1996) and Ratnam, Rao, and Reddy (2011) found that weed interference can decrease chickpea productivity by more than 85%, and Kaushik et al. (2014) observed a loss in productivity of more than 65% that reduced financial gains by 42%. However, weeds do not interfere equally during all stages of crop growth; during some periods, chickpeas can tolerate the presence of weeds without any negative effects on productivity (Al-Thahabi, Yasin, Abu-Irmaileh, Haddad, & Saxena, 1994).

There are three different weed interference periods: the period prior to weed interference (PPWI) that begins with crop emergence and during which the crop may coexist with weeds without decreased productivity; the total period of weed interference prevention (TPIP) that starts with crop emergence and during which weeds should be controlled to enable the crop to reach its productivity potential; and the critical period of weed interference (CPWI), which is the interval between these two periods. Periods of weed interference in agricultural crops can be used to optimize the weed control period (Amaral, Souza, Pavan, Gavassi, & Alves, 2013), thus enabling a reduction in the use of pesticides and/or weeding through the development of bioeconomic models for use in integrated weed management systems (Mohammadi et al., 2005; Amaral et al., 2015) and avoiding crop losses or damages, thereby resulting in an economically viable yield (Tepe, Erman, Yergin, & Bükün, 2011).

Interference periods vary widely depending on factors including environmental conditions and the characteristics of the soil, weed community and the crop itself (Tepe et al., 2011). Chickpeas are very sensitive to weed interference due to their slow growth rate and limited leaf area during the early stages of growth and establishment (Kaushik et al., 2014).

The yield gap in chickpea culture can be narrowed by adopting advanced production technologies that balance nutrition, weed management and the use of high-yielding varieties (Rani & Krishna, 2016). Soil nutrient availability, especially of nitrogen (N), phosphorus (P) and potassium (K), is among the most important factors that affect the competitive relationships between the crop and weeds (Tang et al., 2014).

As a leguminous crop, chickpea fixes N from the atmosphere, but there is strong evidence that it may be inferior to other grain legumes in terms of this function. Therefore, there is a need to determine the level of N needed to obtain higher yieldsof good quality (Rani & Krishna, 2016).

The chickpea is a robust plant, but mineral nutrient limitation is considered a major environmental stressor that contributes to yield loss (Valenciano, Boto, & Marcelo, 2011). Understanding plant responses to fertilizer aids in the development of fertilization strategies and is a key component of integrated weed management programs (Blackshaw et al., 2003).

The aim of this study was to assess the effects of three N topdressing regimes on the critical periods of interference (the PPWI, TPIP and CPWI) for the natural weed community and chickpea productivity. The study attempted to answer the following questions: a) Does N topdressing alter the critical periods of interference? b) Does N topdressing improve chickpea productivity and interfere with the weed community?

Material and methods

During 2011 and 2012, three experiments were performed under field conditions at 21° 14' S latitude and 48° 17' W longitude in the municipality of Jaboticabal, São Paulo State, Brazil at an average altitude of 615 meters above sea level. The climate of the region is defined as tropical and is classified as Cwa.

Climatological data (Table 1) show that the experiments were conducted under similar environmental conditions. Average temperature was similar in both years, although rainfall was much higher in 2012, with a cumulative rainfall of 110.5 mm compared with 44.9 mm in 2011. These moisture variations were mitigated using supplemental irrigation, and sprinklers were used whenever considered necessary based on visual inspection. By the end of the experiment, 400 mm of water had accumulated in both areas following the recommendations of EMBRAPA (2010).

Table 1. Maximum, average and minimum temperatures and monthly rainfall between May and September 2011 and 2012 in Jaboticabal, São Paulo State, Brazil.

Year	Months	Maximum temperature (°C)	Average temperature (°C)	Minimum temperature (°C)	Rainfall (mm)
2011	May	31.60	20.20	8.80	6.50
	June	30.10	16.75	3.40	26.70
	July	31.60	19.10	6.60	0.00
	August	35.40	19.80	4.20	9.40
	September	37.30	22.85	8.40	2.30
2012	May	30.30	19.55	8.80	20.40
	June	30.20	21.00	11.80	48.60
	July	31.70	18.75	5.80	9.00
	August	31.60	21.15	10.70	0.00
	September	36.60	21.40	6.20	32.50

The experiments were in different fields in the different years. The experimental areas were previously used to grow soybean (*Glycine max*) in 2011 and maize (*Zea mays*) in 2012. A composite soil sample was collected seventy days before the sowing of chickpeas, and chemical and physical analyses of the sample are presented in Table 2. Based on the results, dolomitic limestone was applied to raise the base saturation (V%) to 70% in both years.

Table 2. Physical and chemical properties of the soil in which chickpeas were sown in 2011 and 2012 in Jaboticabal, São Paulo State, Brazil.

Soil parameter	Year	
	2011	2012
pH ($CaCl_2$)	5.5	4.5
Organic matter (g dm^{-3})	20.0	19.0
$P_{residue}$ (mg dm^{-3})	69.0	24.0
K^+($mMol_c$ dm^{-3})	3.0	3.4
Ca^{2+}($mMol_c$ dm^{-3})	40.0	11.0
Mg^{2+}($mMol_c$ dm^{-3})	18.0	6.0
$H+Al^{3+}$ ($mMol_c$ dm^{-3})	34.0	42.0
Base saturation ($mMol_c$ dm^{-3})	61.0	20.4
Cation exchange capacity ($mMol_c$ dm^{-3})	95.0	62.4
Fertility rate [V%]	64	33
Clay	546	380
Silt	241	37
Sand	130	245
Grit	83	338
Texture	Clayey	Clayey

Chickpeas (BRS Cícero, Kabuli group) were sown during the first half of May, in both years, under a conventional tillage system and the rate of 14 seeds per meter at a 45-cm inter-row spacing. Seeds were previously treated with thiamethoxam and carboxin + thiram, and fertilization at sowing comprised 150 kg ha^{-1} of formulated fertilizer (04-14-08). Thinning was performed after emergence, leaving 12 plants per meter.

Three doses of N topdressing were used in both years, corresponding to three experiments: I – 0 kg N ha^{-1}; II - 50 kg N ha^{-1}; and III - 75 kg N ha^{-1}. Fertilization was performed at 40 days after sowing when the plants were at the “vegetative growth” phenological stage before flowering.

At each N dose, the treatments consisted of increasing periods of coexistence and weed control; the treatments were analyzed from crop emergence and divided into two groups. In the first group, weeds were allowed to coexist from crop emergence to the end of the respective coexistence period (infested with weeds - IWW): IWW until 0 (IWW_0), 7 (IWW_7), 14 (IWW_{14}), 21 (IWW_{21}), 28 (IWW_{28}), 35 (IWW_{35}), 42 (IWW_{42}), 56 (IWW_{56}), 63 (IWW_{63}), and 140 (IWW_{140}) days after emergence (DAE), after which weeds were controlled and the plots were kept clean until harvest. In the second group, the crop was maintained free of weeds from emergence to the end of the respective control period (free of weeds - FOW): 0 (FOW_0), 7 (FOW_7), 14 (FOW_{14}), 21 (FOW_{21}), 28 (FOW_{28}), 35 (FOW_{35}), 42 (FOW_{42}), 56 (FOW_{56}), 63 (FOW_{63}), and 140 (FOW_{140}); after the indicated periods, weeds were allowed to grow freely in the plots, coexisting with the crop until harvest. Hand weeding was performed to maintain the plots “clean” of weeds.

The experiments were conducted using a randomized block design with four replicates. Each experimental plot comprised five six-meter-long sowing rows, resulting in a total area of 13.5 m^2. The three central rows were samples and evaluated, and one meter was discarded at each end, resulting in a final useful area of 5.4 m^2.

In the treatments corresponding to the weed-infested periods, the weed community was sampled at the end of each predetermined period by collecting weed samples from 0.75 m^2 of the useful area of the respective plots, corresponding to three subsamples of 0.25 m^2, using frames that were randomly placed in the plot row and inter-row areas. The weed species were identified, separated and dried in a convection drying oven at 70°C for 96h for subsequent measurement of shoot dry mass (DM). In the treatments corresponding to weed-free periods, the weed community was evaluated at 70 DAE (before harvest).

The chickpea crops were harvested at 140 DAE, when the grain moisture contents ranged from 13 to 15%. The chickpea productivity data were fitted to a Boltzmann sigmoidal regression model to estimate the PPWI, TPIP, and CPWI, as performed by Kuva, Pitelli, Christoffoleti, and Alves (2000) and Cardoso, Alves, Severino, and Vale (2011): $y = [(P1 - P2) / (1 + e (x - xi) / dx))] + P2$, where y is chickpea yield (t ha^{-1}) according to the period of coexistence or control; P1 is the maximum production (t ha^{-1}) obtained in plants without weed interference throughout the cycle; P2 is the minimum production (t ha^{-1}) obtained in plants coexisting with weeds during the period; (P1 - P2) is the yield losses (t ha^{-1}); x is the upper limit of the coexistence control period (days); xi is the upper limit of the interaction or control period, which corresponds to the intermediate value between the maximum and minimum output (days); and dx indicates the rate of production loss of due to the duration of coexistence [(t ha^{-1}) dia^{-1}]. The periods of interference were determined by accepting productivity losses of 2.5, 5, and 10% compared with those obtained in plots that were maintained free of weeds throughout the crop cycle.

The percentage losses compared with the weed-free plots were calculated based on grain productivity data as follows: PL (%) = ((Ra - Rb)/Ra) x 100, where PL is the percent loss of chickpea productivity; Ra is the chickpea yield in the coexistence periods; and Rb is the chickpea yield in the weed control period. These data were correlated with the accumulated weed dry mass using a linear or quadratic regression model.

Result

In 2011, the weed community comprised 15 species belonging to 11 botanical families; Amaranthaceae and Poaceae were the most represented, at three species each. However, Amaranthaceae and Brassicaceae had the highest density values, with 36.49 and 33.29% of the total number of individuals sampled (10,430), respectively. Conversely, the Poaceae family only accounted for 5.81% of the individuals sampled, less than Portulacaceae (10.25%). The family Brassicaceae was only represented by *Raphanus raphanistrum* in 2011. During the periods of infestation in 2011, *R. raphanistrum* and *Amaranthus viridis* had the highest total weed dry mass, corresponding to 72.58 and 12.38% of the total weed dry mass (36.16 kg accumulated in 180 m^2 sampled), respectively.

In 2012, the weed community comprised 23 weed species belonging to 13 families, yielding a total dry mass accumulation of 18.46 kg over 180 m^2. The families with the greatest species densities were Brassicaceae (35.33%), Asteraceae (17.09%) and Portulacaceae (14.92%). In 2012, the family Amaranthaceae only accounted for 7.99% of 11,602 individuals sampled, a value that was lower than that for Cyperaceae (8.46%) and Solanaceae (8.20%). The family Asteraceae was represented by five species in 2012 but was represented only by *Parthenium hysterophorus* in 2011. The family Brassicaceae had the highest abundance in terms of the number of individuals and was represented by *R. raphanistrum*, *Lepidium virginicum* and *Coronopus didymus*, which accounted for 63.19, 26.06, and 10.76% of the total number of individuals of the family, respectively. The species *R. raphanistrum* and *Bidens pilosa* were the most dominant among the species with the highest densities (*A. viridis*, *B. pilosa*, *C. didymus*, *Cyperus rotundus*, *L. virginicum*, *Nicandra physaloides*, *P. hysterophorus*, *Portulaca oleracea,* and *R. raphanistrum*) in the analyzed agro-ecosystem and exhibited the highest accumulations of dry mass (67.72 and 10.21%, respectively).

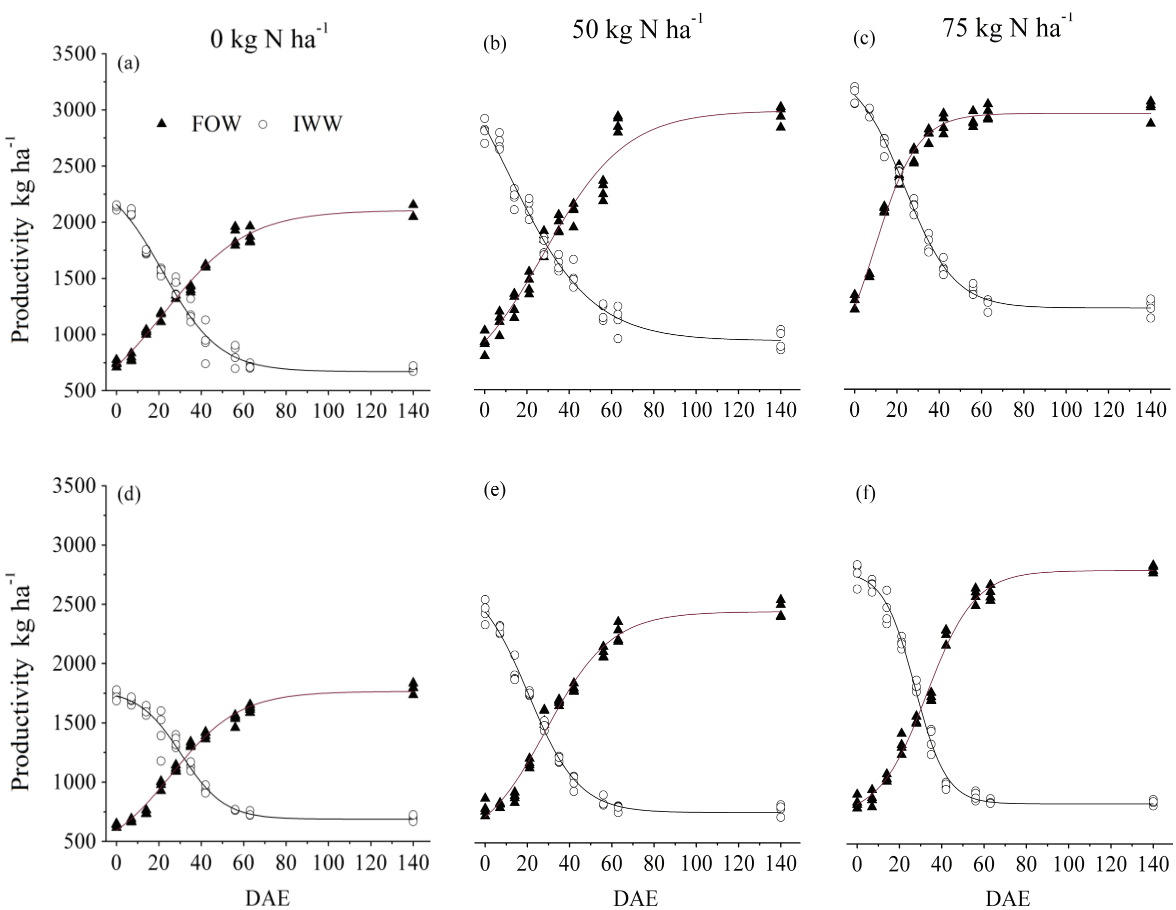
Higher N doses caused reduced species diversity and plant density in both years, whereas the opposite was true of biomass; N fertilization led to increased biomass accumulation. *R. raphanistrum* was among the most important species regardless of N dose applied, both in 2011 and 2012.

Figure 1 presents curves fitted to Boltzmann's equation; according to this model, productivity declined from 2,450.34 to 670.02 kg ha^{-1} (0 kg N ha^{-1}), from 3,876.75 to 925.59 kg ha^{-1} (50 kg N ha^{-1}) and from 3,302.40 to 1,205.85 kg ha^{-1} (75 kg N ha^{-1}) in 2011 (based on maximum and minimum yields), representing decreases of 72.66, 76.12, and 63.49%, respectively, with increasing N doses. Productivity decreases from 1,779.58 to 687.79 kg ha^{-1} (0 kg N ha^{-1}), from 2,786.67 to 758.55 kg ha^{-1} (50 kg N ha^{-1}) and from 2,865.24 to 846.84 kg ha^{-1} (75 kg N ha^{-1}) were obtained in 2012, representing decreases of 61.35, 72.78, and 70.44%, respectively. These results demonstrate the high susceptibility of chickpeas to weed interference.

Considering 2.5, 5, and 10% chickpea productivity losses as acceptable, the presence of weeds affected the crop at 6, 7, and 11 DAE (PPI), respectively, in 2011 when using 0 kg N ha^{-1} (Figure 1a; Table 3). The results also showed that weeds should be controlled until 82, 76, and 61 DAE to achieve maximum production losses of 2.5, 5, and 10%, respectively (TPIP). Thus, the periods during which weeds should be controlled (CPWI) are as follows: from 6 to 82 DAE (2.5% acceptable productivity loss), from 7 to 76 DAE (5% acceptable productivity loss) and from 11 to 61 DAE (10% acceptable productivity loss). Following the TPIP, weed control did not increase chickpea productivity.

Coexistence with the weed community began to affect crop productivity at 4, 5, and 9 DAE (PPI) in the experiment using 50 kg N ha^{-1} in 2011 (Figure 1b), assuming chickpea productivity losses of 2.5, 5, and 10% (Table 3), respectively. Furthermore, weed control for maximum losses of 2.5, 5, and 10% should be performed until 69, 65, and 57 DAE, respectively (TPIP). Thus, the periods during which weeds should be controlled (CPWI) are as follows: from 4 to 69 DAE (2.5% acceptable productivity loss), from 5 to 65 DAE (5% acceptable productivity loss) and from 9 to 57 DAE (10% acceptable productivity loss).

Also in 2011, PPWIs of 9, 10, and 14 DAE and TPIPs of 45, 40 and 31 were obtained using 75 kg N ha^{-1} (Figure 1c) for chickpea productivity losses of 2.5, 5, and 10%, respectively (Table 3). Thus, the periods during which weeds should be controlled (CPWI) are as follows: from 9 to 45 DAE (2.5% acceptable productivity loss), from 10 to 40 DAE (5% acceptable productivity loss) and from 14 to 31 DAE (10% acceptable productivity loss).



	▲ FOW		○ IWW	
(a)	$y = \frac{-1832.42}{1 + e^{\frac{(x-22.34)}{19.64}}} + 2105.98$	R^2: 0.98	$y = \frac{1780.33}{1 + e^{\frac{(x-21.81)}{13.41}}} + 670.02$	R^2: 0.97
(b)	$y = \frac{-2495.48}{1 + e^{\frac{(x-27.75)}{19.54}}} + 2928.62$	R^2: 0.95	$y = \frac{2951.16}{1 + e^{\frac{(x-10.76)}{19.78}}} + 925.59$	R^2: 0.97
(c)	$y = \frac{-2373.92}{1 + e^{\frac{(x-9.19)}{10.20}}} + 2900.02$	R^2: 0.98	$y = \frac{2096.54}{1 + e^{\frac{(x-23.72)}{11.72}}} + 1205.85$	R^2: 0.99
(d)	$y = \frac{-1407.61}{1 + e^{\frac{(x-25.77)}{16.11}}} + 1765.49$	R^2: 0.99	$y = \frac{1091.79}{1 + e^{\frac{(x-30.61)}{10.15}}} + 687.79$	R^2: 0.97
(e)	$y = \frac{-2033.21}{1 + e^{\frac{(x-28.74)}{15.47}}} + 2480.61$	R^2: 0.98	$y = \frac{2028.12}{1 + e^{\frac{(x-20.52)}{11.91}}} + 758.55$	R^2: 0.99
(f)	$y = \frac{-2135.03}{1 + e^{\frac{(x-32.93)}{11.35}}} + 2869.02$	R^2: 0.99	$y = \frac{2018.40}{1 + e^{\frac{(x-27.33)}{7.45}}} + 846.84$	R^2: 0.99

Figure 1. Chickpea productivity as a function of the periods of weed coexistence and absence in 2011 (a, b, c) and 2012 (d, e, f) with topdressings of 0 kg N ha^{-1} (a, d), 50 kg N ha^{-1} (b, e) and 75 kg N ha^{-1} (c, f). One curve represents the productivity of initially weed-infested chickpeas (○ IWW), and the second represents that of initially weed-free chickpeas (▲ FOW).

Table 3. Period prior to weed interference (PPWI), total period of weed interference prevention (TPIP) and critical period of weed interference (CPWI) as a function of the tolerated reductions in yield for the experiments conducted in 2011 and 2012 with topdressings of 0, 50, and 75 kg N ha^{-1}.

Year	Topdressing	Tolerated reduction								
		2.5%			5%			10%		
		Period (days after emergence)								
		PPWI	TPIP	CPWI	PPWI	TPIP	CPWI	PPWI	TPIP	CPWI
2011	0 kg N ha^{-1}	6	82	6-82	7	76	7-76	11	61	11-61
	50 kg N ha^{-1}	4	69	4-69	5	65	5-65	9	57	9-57
	75 kg N ha^{-1}	9	45	9-45	10	40	10-40	14	31	14-31
2012	0 kg N ha^{-1}	8	59	8-59	11	64	11-64	17	55	17-55
	50 kg N ha^{-1}	9	59	9-59	10	57	10-57	13	50	13-50
	75 kg N ha^{-1}	7	63	7-63	10	61	10-61	15	53	15-53

In 2012, in the experiment using 0 kg N ha^{-1} (Figure 1d) and accepting 2.5, 5, and 10% crop productivity losses (Table 3), the PPWIs were 8, 11, and 17 DAE, respectively, and the TPIPs were 59, 64, and 55 DAE. Consequently, the CPWIs were from 8 to 59 DAE (51 days), from 11 to 64 DAE (53 days) and from 17 to 55 DAE (38 days), respectively.

Also during 2012, in the experiment using 50 kg N ha^{-1} (Figure 1e) and accepting productivity losses of 2.5, 5, and 10%, the PPWIs were 9, 10, and 13 DAE, respectively, and the TPIPs were 59, 57, and 50 DAE. Consequently, the CPWIs obtained in this experiment were from 9 to 59 DAE (50 days), from 10 to 57 DAE (47 days) and from 13 to 50 DAE (47 days), respectively (Table 3).

Also in 2012, PPWIs of 7, 10, and 15 DAE, TPIPs of 63, 61 and 53 DAE and CPWIs from 7 to 63 DAE (56 days), from 10 to 61 DAE (51 days) and from 15 to 53 DAE (38 days) were obtained for productivity losses of 2.5, 5, and 10%, respectively, (Table 3) when using 75 kg N ha^{-1} (Figure 1f).

Comparing treatments in the total absence of weeds (FOW_{140}) with the treatments in the presence of weeds throughout the entire crop cycle (IWW_{140}), the data for 2011 demonstrate grain productivity decreases of 67.16, 67.65, and 58.69% when using 0, 50, and 75 kg N ha^{-1}, respectively, and the maximum productivities obtained were 2,101, 2,890, and 2,936 kg ha^{-1} (FOW_{140}), respectively; these results demonstrate the high susceptibility of chickpeas to weed interference.

Chickpea yields in the IWW_0 periods for the 2011 harvest were 2,138, 2,755, and 3,051 kg ha^{-1} when fertilized with 0, 50, and 75 kg N ha^{-1}, respectively. The 2012 harvest showed lower yields than those obtained in 2011; total yields were 1,733, 2,482, and 2,846 kg ha^{-1} for the treatments fertilized with 0, 50, and 75 kg N ha^{-1}, representing decreases of 18.94, 9.91, and 6.72%, respectively, when compared with the maximum yields of the previous year. The productivities measured for the FOW_{140} periods were 2,101, 2,890, and 2,936 kg ha^{-1} in 2011 and 1,792, 2,501, and 2,883 in 2012, representing decreases of 14.71, 13.46, and 1.80% in the treatments fertilized with 0, 50, and 75 kg N ha^{-1}, respectively.

Decreased grain productivity was positively correlated with weed dry mass accumulation ($p < 0.0001$) in the three experiments conducted in 2011 (Figure 2a, b, and c), and the productivity losses were directly proportional to the dry mass of the weed community in all experiments, regardless of N fertilization dose. In 2011, the relationship between weed dry weight and seed yield loss could be described by a linear regression model. In contrast, the increase in weed dry weight also led to seed yield loss in 2012, but the weed dry weight associated with maximum crop yield was identified by polynomial regression analysis, which indicated a quadratic polynomial response of seed yield loss to weed dry weight.

Discussion

The weed community in the chickpea crops differed between 2011 and 2012 in terms of species composition, density and dry mass accumulation. These differences might be explained by the different agricultural practice histories used in preceding crops, which might have benefited some species over others by creating the appropriate characteristics for the occupation and/or establishment of specific species in the niche. In addition to the previous agricultural practices, the N fertilization might have affected the weed flora because the treatments with higher N doses exhibited decreased numbers and diversity of species in both years (data not shown). For some plant species, especially grasses, the use of high doses of fertilizers might negatively affect species diversity (Lorenzo, Michelea, Sebastian, Johannes, & Angelo, 2007); this suggests an inverse relationship between soil nutrient availability and plant species diversity. The species *R. raphanistrum*, *A. viridis*, and *B. pilosa* had a higher incidence in both years. Amaral et al. (2015), while studying the interference of *A. viridis, B. pilosa, R. raphanistrum*, *C. rotundus*, *Digitaria nuda*, and *Eleusine indica* on the vegetative growth of chickpea, observed that *A. viridis*, *D. nuda*, and *E. indica* were the most competitive and aggressive species; these species compromised crop growth until 90 days after emergence.

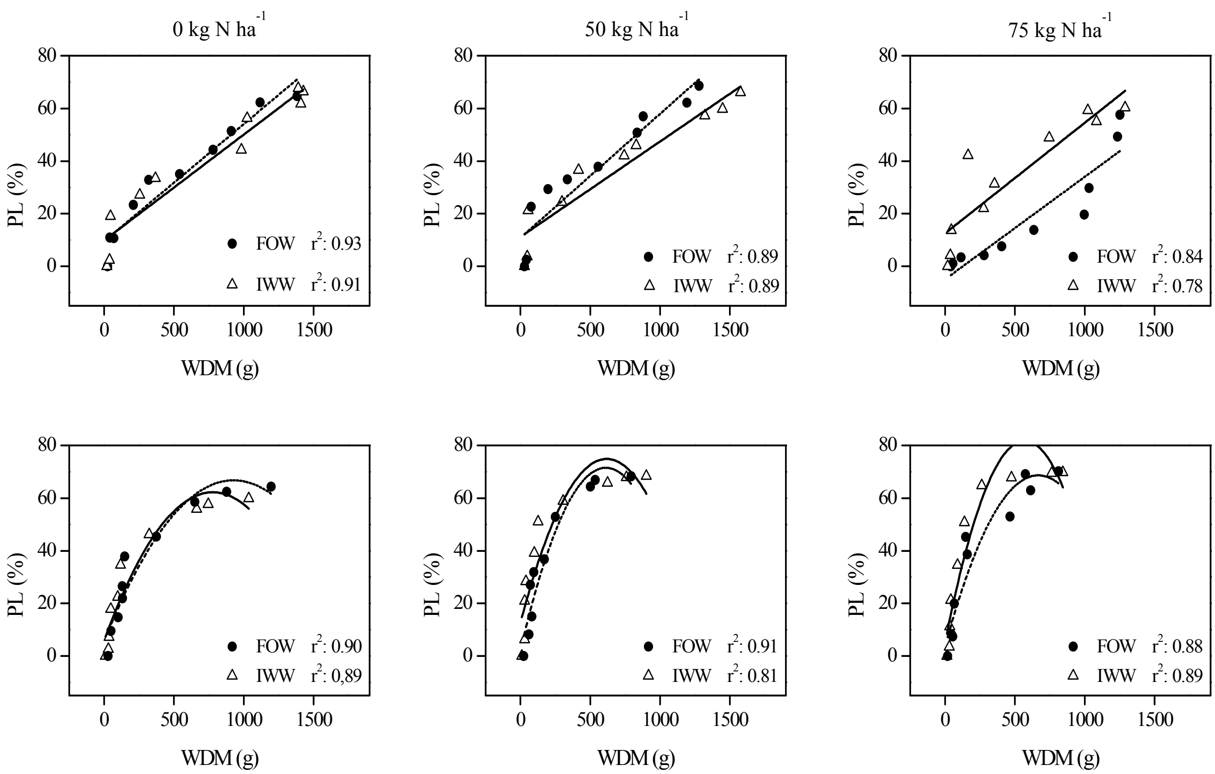


Figure 2. Percent loss (PL) of chickpea productivity as a function of accumulated weed dry mass (WDM) in the treatments subjected to different periods of coexistence in 2011 (a, b, c) and 2012 (d, e, f) with topdressing fertilization at 0 kg N ha-1 (a, d), 50 kg N ha-1 (b, e), and 75 kg N ha-1 (c and f). FOW: initially free of weeds; IWW: initially infested with weeds, $p < 0.0001$.

In both years, longer duration of weed pressure on the crop caused higher chickpea productivity losses, thereby indicating the crop sensitivity to coexistence with a weed community, regardless of the use of N topdressing or the composition of that community. Weed interference has effects on crops that are often irreversible, and the recovery of growth, development or productivity might not occur after removing the stress caused by the coexistence of weeds (Bressanin, Nepomuceno, Martins, Carvalho, & Alves, 2013). The advantages of topdressing fertilization for plants grown in the absence of weeds are indisputable, but the presence of weeds generates great uncertainty about the effectiveness of fertilization. Nitrogen is the nutrient that weeds and crop species most compete for (Shafiq, Hassan, Ahmad, & Rashid, 1994). Nitrogen fertilization might increase the competitive ability of the crop species, thereby decreasing the competitive pressure and weed suppression in the crop (Shafiq et al., 1994). The decrease in species diversity might also be related to crop growth, and higher N doses result in shorter critical weed-free periods due to the resulting rapid shoot growth (Yamauti, Alves, & Bianco, 2012).

The lower productivity observed in the experiments conducted in 2012 compared with those conducted in 2011 might be due in part to the weed diversity (15 species in 2011 vs. 23 in 2012), the previous crop (soybean in 2011 vs. maize in 2012), environmental conditions and soil characteristics. However, the yields in the FOW_0 of the plots (mean: 1,732.8 kg ha^{-1}) remained within the expected productivity range for the cultivar (from 1,600 to 2,700 kg ha^{-1}; EMBRAPA, 2010), even in the most unfavorable soil without topdressing (the experiment with the lowest productivity - 2012, experiment I).

The experimental PPWIs of both years ranged from 4 to 7 DAE if a productivity loss from 2.5 to 10% was considered acceptable, and they ranged from 5 to 11 DAE when considering a 5% productivity loss. Similar PPWI values have been estimated in other species belonging to the family Fabaceae, including the common bean (*Phaseolus vulgaris*) at 4 DAE (Borchartt, Jakelaitis, Valadão, Venturoso, & Santos, 2011), soybean (*Glycine max*) with values ranging from 11 to 17 DAE (Silva et al., 2009) for 5% losses only, and the Jam chickpea cultivar (also from the Kabuli group) in Tabriz, northwestern Iran, for which a PPWI of 17 DAE and a TPIP of 60 DAE were obtained in 2003 (Mohammadi et al., 2005). Al-Thahabi et al. (1994) observed a chickpea CPWI in Jordan ranging from

35 to 49 DAE. The low PPI values of the chickpea crop might be explained by its slow growth, open canopy and short stature, which reduce the ability of the crop to compete with weeds (Mohammadi et al., 2005).

In 2011, the increased use of N shortened the CPWI, but this result was not observed in 2012.Therefore, under the experimental conditions in this study, there was no relationship between the amount of N topdressing applied and CPWI.

The increase in the period of crop coexistence with the weed community drastically reduced the observed productivity, regardless of the absence or presence of fertilization. Yield decreases of greater than 50% were observed compared with plants that remained weed-free throughout the crop cycle (FOW_{140}) in all experiments. Most weeds exhibit faster initial growth than chickpeas, providing a great competitive advantage for weed populations, thereby inhibiting crop growth and reducing the incidence of light, which might affect photosynthesis and crop yield (Tepe et al., 2011). Al-Thahabi et al. (1994) observed that chickpea production was decreased by 81% due to weed interference, thus confirming the sensitivity of the crop to this factor. The cited authors noted a significant negative correlation between weed dry mass accumulation and crop seed production, a finding that was primarily attributed to a decrease in the number of pods per plant and the 100-seed weight.

The difference observed between the periods of interference from one harvest to the other suggests that critical periods can depend on several factors, including temperature and soil moisture, weed density, weed species composition (Tepe et al., 2011), time to weed emergence (Scholten, Parreira, & Alves, 2011), climate (Mohammadi et al., 2005; Tepe et al., 2011), drought (Parreira, Barroso, Fernandes, & Alves, 2015), light intensity (Retta, Vanaderlip, Higgins, Moshier, & Feyerherm, 1991), soil fertility (Mohammadi et al., 2005; Yamauti et al., 2012), and the characteristics of the crop itself, including species and cultivar used (Parreira, Alves, Lemos, & Portugal, 2014), crop sowing density and distribution patterns (Scholten et al., 2011), and sowing season (Mohammadi et al., 2005).

The need for fertilizer when growing chickpeas is not very well known and requires further study. Although chickpea is a legume, it responded positively to topdressing with N fertilizer. Fertilization might therefore give the crop a competitive advantage over the weed community. The comparison between the weed-infested and weed-free treatments during 2011 in the experiments with N topdressing showed increases of 37.55 and 28.86% (50 kg N ha^{-1}) and 39.74 and 42.70% (75 kg N ha^{-1}) compared with the experiment in the absence of fertilization for the periods FOW and IWW, respectively. In 2012, the observed productivity gains were even larger at 39.56 and 43.22% (50 kg N ha^{-1}) and 60.88 and 64.22% (75 kg N ha^{-1}) for the periods FOW and IWW, respectively. Methods such as topdressing with N-based fertilizer have been advocated for bean crops due to the resulting increases in grain yield (Gomes Jr. et al., 2005). Bressanin et al. (2013) noted that topdressing with N fertilizer increased the productivity of the 'Rubi' bean, even in the presence of weeds, and favored the crop competitively, thereby increasing the period prior to weed interference (PPI).

Topdressing with N fertilizer led to productivity gains of 617 and 913 kg ha^{-1} in 2011 and to gains of 749 and 1,113 kg ha^{-1} in 2012 when applied at the rates of 50 and 70 kg ha^{-1} N, respectively. The average annual price of the fertilizer used in the topdressing (urea) (CONAB, 2012) was U$D 0.61 per kilogram (base year 2012), and between 112 and 167 kg urea is necessary for application at the rates of 50 and 75 kg N ha^{-1}. Furthermore, the technical coefficient for chickpea fertilization (EMBRAPA, 2010) and the machine-hour cost of the tractor and fertilizer spreader for June 2012 (CONAB, 2012) should be added to the cost. Finally, the international market price of chickpeas is approximately U$D 1 per kilogram (FAO, 2015; Where Food Comes From, 2014). Based on these numbers, topdressing with N fertilizer at the rates of 50 to 75 kg N ha^{-1} would cost between U$D 222.40 to 256.81 ha^{-1} and generate a return between approximately U$D 617.00 to 1113.00 ha^{-1}.

Conclusion

In conclusion, the presence of weeds negatively affects chickpea production and can cause considerable yield losses, rendering the crop economically unfeasible. The CRWI for chickpea production during both years was affected regardless of the N topdressing dose and ranged from 5 to 76 DAE in 2011 and 10 to 64 DAE in 2012, assuming an acceptable productivity loss of 5%. Although the critical periods of interference obtained in the 50 and 75 kg N ha^{-1} treatments were similar to those obtained in the treatments without fertilization (0 kg N ha^{-1}), N fertilization increased chickpea productivity, leading to economic gains.

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