



Irrigation periods, broomrape control treatments and the growth performance of pea (*Pisum sativum*)

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ABSTRACT

Pea (*Pisum sativum* L.) is one of the most important vegetable crops but it is threatened by the holoparasitic plant broomrape (*Orobancha crenata* Forsk). Therefore, two field experiments were conducted in Sakha Agriculture Research Station, Egypt, during 2015–16 and 2016–17 to evaluate the effect of interaction between irrigation periods, and broomrape control treatments to control broomrape, yield and its components in pea and glyphosate residues in pea seeds. The results illustrated that irrigation period after 14 days followed by 21 days decreased broomrape growth and gave rise to the highest values for pea yield and its components. All broomrape control treatments significantly decreased broomrape growth and significantly increased yield and its components. No residues of herbicide (glyphosate at 6.35 g a.i./ha) were detected in pea seeds at harvest. These results indicated that in heavily infested soil with broomrape, irrigation should be done at 14 days interval and glyphosate should be sprayed twice. This gave best broomrape control and increased pea seed yield (t/ha), without any residues in pea seeds at harvest.

Key words: Glyphosate, Irrigation period, *Orobancha crenata*, *Pisum sativum*, Residue

Pea (*Pisum sativum* L.) is considered as the second most important vegetable crop cultivated in the world and first important crop in Europe (Faostat 2014). However, pea production can be damaged by a number of diseases and pests (Rubials *et al.* 2014). Broomrape (*Orobancha crenata*) are noxious root parasitic weeds that reduce quality and quantity of legumes and several other crops. This parasitic weed is difficult to control because it is closely associated with the host root and it remains underground for most of the life cycle. *Orobancha* infestation in pea fields can lead to yield losses up to 80% and result in the abandonment of pea cultivation infested areas (Rubials *et al.* 2003). Mauromicale *et al.* (2008) reported that *Orobancha* plants decreased the aboveground mass of the tomato plant. Muller-Strover *et al.* (2009) showed that this weed species in central Europe is the most spread from the Orobanchaceae family causing a serious damage to many crops, particularly tobacco, hemp, and tomato.

Nasser and Mekky (2002) found that irrigation after two-week-interval followed by four-week-interval decreased the number and dry weight of broomrape. Also, Fakkar *et al.* (2016) revealed that irrigation at 100% FC (Field capacity) decreased number and dry weight of broomrape spikes/m², delaying broomrape emergence above soil surface and increased faba bean seed yield and its components as compared with depletion at 60% FC. Ashrafi *et al.* (2009) reported that solarization destroyed about 95% buried viable seeds and induced secondary dormancy in the remaining seeds. Boz *et al.* (2012) reported 100% reduction regardless of the duration of solarization to *Orobancha ramosa*. Application of glyphosate twice at a rate of 8.2 g a.i./ha, gave rise to 99.1% and 97.8% reduction of broomrape and increased bean seed yield by 149.5% and 141.5% compared to untreated plots (El-Metwally *et al.* 2013). Glyphosate residue became un-decorated in the soil after 40 days from its application. At end of the experiment, there was no residue in clover plants (Soliman 2016). The aim of the present study was to evaluate the effect of irrigation periods, broomrape control treatments and their interaction on *Orobancha crenata* control and seed yield of pea, and to determine glyphosate residues in pea seeds.

MATERIALS AND METHODS

Two field experiments were conducted during winter season of 2015–16 and 2016–17 at Sakha Agriculture Research Station, Egypt. Treatments of each experiment were coordinated in a split-plot design with four replicates.

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The irrigation periods were arranged at random in the main plots and broomrape control treatments were randomly arranged in the sub-plots. The experimental site at the field was naturally heavily and homogeneously infested by broomrape seeds. Seeds of pea cv. Master B were sown in hills. The sowing dates were achieved on 22nd and 29th October in 2015–16 and 2016–17 seasons respectively. All cultural practices were done according to GAP (Good Agricultural Practices). Treatments were: Main plots (Irrigation periods), Irrigation after 14, 21 and 28 days. Subplot (broomrape control treatments): First treatment, Glyphosate 48% WSC at a rate of 6.35 g a.i./ha, applied twice with 21 days interval; first one was applied at flowering stage of pea at 35 days from sowing. Second, Glyphosate at a rate of 6.35 g a.i./ha, applied twice with 21 days interval; first one was applied at 40 days from the sowing of pea. Third, Glyphosate at a rate of 5.29 g a.i./ha, applied twice with 21 days periods; first one was applied at flowering stage of pea 35 days from the sowing of pea. Fourth, Glyphosate at a rate of 5.29 g a.i./ha, applied twice with 21 days interval; first one applied at 40 days from the sowing of pea. Fifth, soil solarization+ glyphosate at a rate of 6.35 g a.i./ha, applied at flowering stage of pea 40 days from sowing. Sixth, soil solarization + glyphosate at a rate of 5.29 g a.i./ha. applied at flowering stage of pea 35 days from sowing. Seventh, soil solarization only (were done according to (Arslan *et al.* 2012)). Hand pulling (twice) and Control (untreated).

Broomrape spikes were hand pulled at random from m² area for each sub-plot after 30 days from herbicide application to estimate the broomrape spike length, number of broomrape spikes/m², number of broomrape spikes/plant and fresh weight of broomrape spikes (g/m²). The effect of

studied treatments on broomrape was estimated as percent reduction, which was calculated as follows.

$$\text{Reduction (\%)} = \frac{(A-B)}{A} \times 100 \quad (1)$$

where A, number or weight of broomrape spikes in the untreated plot; B, number or weight of broomrape spikes in the treated plot.

At harvest, plants were harvested to determine the plant height, dry weight, number of pods, fresh weight of pods/plant, 100-seed weight and pea seed yield. Seed yield was recorded from the seeds of harvested plants/plot and converted to t/ha. The effect of the studied treatments on pea plants was estimated as improvement which was calculated as:

$$\text{Improvement (\%)} = \frac{(B-A)}{B} \times 100 \quad (2)$$

where A, untreated; B, treated.

From each treatment, pea seeds samples were taken at harvest time for residue determination. The pea seeds were ground to be powder. Five grams were taken for mixing with 10 ml acetonitrile, 2 gMgSO₄ and 0.5 g. NaCl. The mixture was shaken for 5 min and sonicated for ten min. The tubes were centrifuged at 3000 rpm for five min at room temperature. The residues of glyphosate herbicide in pea seeds were extracted according to the methods of Jiang *et al.* (2009). The active ingredients of glyphosate were determined by HPLC instrument according to this method of Luke *et al.* (1981)

Data were statistically analyzed according to Gomez and Gomez (1984) for each season and combined over both seasons of analysis. The comparisons of means were

Table 1 Effect of irrigation periods and broomrape control treatments on broomrape growth at 30 days from glyphosate application (Pooled data 2015–16, 2016–17)

Treatment	Broomrape spike length (cm)	No. of broomrape spikes/m ²	No. of broomrape spikes/plant	Fresh weight of broomrape spikes (g/m ²)
<i>Irrigation period after</i>				
14 days	15.1a	7.3a	2.2a	23.1a
21 days	16.0b	8.8b	2.5b	34.9b
28 days	18.6c	12.4c	4.0c	55.5c
<i>Broomrape control treatments</i>				
Glyphosate (6.35 g a.i./ha) twice at 35 and 56 days	8.7 f	3.7 f	1.5 e	8.2 e
Glyphosate (6.35 g a.i./ha) twice at 40 and 61 days	8.8 f	4.0 f	1.6 e	9.2 e
Glyphosate (5.29 g a.i./ha) twice at 35 and 56 days	10.8 de	5.6 e	1.8 e	12.4 cd
Glyphosate (5.29 g a.i./ha) twice at 40 and 61 days	11.0 e	5.8 e	2.3 d	13.0 d
Soil solar. + glyphosate (6.35 g a i./ha) at 35 days	12.0 d	6.7 cd	2.3 d	12.8 cd
Soil solar. + glyphosate (5.29 g a i./ha) at 35 days	12.2 d	7.4 d	2.9 c	13.1 d
Soil solarization only	19.4 c	9.4 c	3.1 b	15.2 c
Hand pulling (twice)	23.0 b	11.3 b	2.8 bc	47.1 b
Control (un-treated.	53.6 a	33.2 a	9.0 a	214.9 a

Soil Solar F, Soil solarization in months (August, September, and October). Significant at P <0.005

Table 2 Effect of irrigation periods and broomrape control treatments on seed yield and yield components at harvest (Pooled data 2015–16, 2016–17)

Treatment	Plant height (cm)	Dry weight/plant (g)	No. of pods/plant	Weight of pods/plant (g)	100-seed weight (g)	Seed yield (t/ha)
<i>Irrigation period after</i>						
14 days	60.07a	26.66a	27.68a	69.05a	28.09a	4.22a
21 days	56.78b	24.91b	24.69b	61.71b	27.74b	3.89ab
28 days	48.96c	21.54c	22.12c	53.96c	25.53c	3.41c
<i>Broomrape control treatment</i>						
Glyphosate (6.35 g a.i./ha) twice at 35 and 56 days	62.65 a	29.87 a	33.53 a	7.30 a	31.99 a	5.83a
Glyphosate (6.35 g a.i./ha) twice at 40 and 61 days	60.81 ab	28.45ab	30.94 ab	72.71 ab	31.66 a	5.14a
Glyphosate (5.29 g a.i./ha) twice at 35 and 56 days	59.29 b	28.38 ab	29.22 b	70.30 b	29.19 ab	4.34ab
Glyphosate (5.29 g a.i./ha) twice at 40 and 61 days	60.29 ab	27.10 b	25.78 c	67.54 bc	29.16 ab	4.08ab
Soil solar. $\bar{p}$ + glyphosate (6.35 g a i./ha) at 35 days	60.03 ab	26.27 bc	25.21 c	64.39 bc	28.70 b	3.89b
Soil solar. + glyphosate (5.29 g a i./ha) at 35 days	59.01 b	24.11 c	21.92 d	62.89 c	27.88 c	3.48bc
Soil solarization only	54.76 c	22.35 bc	19.28 de	59.08 d	26.78 cd	3.34c
Hand pulling (twice)	44.46 d	19.77 d	18.57 e	51.83 e	20.73 d	0.19d
Control (un-treated.	32.54 e	7.06 e	10.01 f	18.42 f	14.99 e	1.2e

Soil Solar $\bar{p}$, Soil solarization in months (August, September, and October). Significant at $P < 0.005$

Table 3 Effect of interaction between irrigation periods and broomrape control treatments on broomrape growth (Pooled data 2015/2016 and 2016/2017)

Irrigation period	Broomrape control treatment	Broomrape spike length (cm)	No. of broomrape spikes/m ²	No. of broomrape spikes/plant	Fresh weight of broomrape spikes (g/m ²)
14 days at 2 W.A.S.	Glyphosate (6.35 g a.i./ha) twice at 35 and 56 days	6.9 l	2.7 ij	1.0h	6.4 kl
	Glyphosate (6.35 g a.i./ha) twice at 40 and 61 days	7.8 kl	2.8ij	1.0 h	6.8 k
	Glyphosate (5.29 g a.i./ha) twice at 35 and 56 days	9.5 kl	3.6 ij	1.1 h	9.0 ij
	Glyphosate (5.29 g a.i./ha) twice at 40 and 61 days	9.9 k	4.0 h	1.7 gh	9.2 ij
	Soil solar. $\bar{p}$ + glyphosate (6.35 g a i./ha) at 35 days	11.8 i	4.8 gh	2.3 f	9.3 ij
	Soil solar. + glyphosate (5.29 g a i./ha) at 35 days	12.4 gh	5.4 gh	2.5 ef	9.6 ij
	Soil solarization only	16.4 fg	5.0 gh	2.6 ef	14.7h
	Hand pulling (twice)	20.7de	9.1 ef	2.7ef	33.9 e
	Control (un-treated.	49.1c	29.8 c	8.8 b	116.0 c
21 days at 2 W. A. S	Glyphosate (6.35 g a.i./ha) twice at 35 and 56 days	8.5 kl	2.3 i	1.0h	3.7 L
	Glyphosate (6.35 g a.i./ha) twice at 40 and 61 days	8.7 kl	2.5 j	1.0 h	6.8 k
	Glyphosate (5.29 g a.i./ha) twice at 35 and 56 days	10.3 ij	3.6 i	1.4 gh	9.2 ij
	Glyphosate (5.29 g a.i./ha) twice at 40 and 61 days	10.6 ij	4.0 gh	1.8 gh	9.6 ij
	Soil solar. $\bar{p}$ + glyphosate (6.35 g a i./ha) at 35 days	11.0 ij	4.7gh	1.8 g	9.6 ij
	Soil solar. + glyphosate (5.29 g a i./ha) at 35 days	11.6 ij	6.3 gh	2.0 ef	9.8 j
	Soil solarization only	18.9 f	4.9 gh	2.0 ef	17.7 h
	Hand pulling (twice)	22.0 e	10.5 ef	2.7 ef	43.8 de
	Control (un-treated.	52.3b	32.6 b	8.2 bb	214.3 b
28 days	Glyphosate (6.35 g a.i./ha) twice at 35 and 56 days	10.0 j	5.9 gh	2.5 ef	14.0 i
	Glyphosate (6.35 g a.i./ha) twice at 40 and 61 days	10.4 ij	7.0 i	2.7 ef	14.1 i
	Glyphosate (5.29 g a.i./ha) twice at 35 and 56 days	12.3 gh	8.7ef	3.0 ef	18.3 h
	Glyphosate (5.29 g a.i./ha) twice at 40 and 61 days	12.3 gh	9.5 f	3.0 ef	19.5 g
	Soil solar. $\bar{p}$ + glyphosate (6.35 g a i./ha) at 35 days	12.9 h	10.5 e	3.5 e	19.7 g
	Soil solar. + glyphosate (5.29 g a i./ha) at 35 days	13.3 g	10.9 de	4.1cd	20.8 g
	Soil solarization only	20.8 de	9.7 f	4.5 d	25.5 f
	Hand pulling (twice)	26.4 d	14.3 d	4.0 c	63.6d
	Control (un-treated)	59.3a	37.2 a	10.0 a	314.5 a

Soil Solar $\bar{p}$, Soil solarization in months (August, September, and October). Significant at $P < 0.005$

Table 4 Effect of interaction between irrigation periods and broomrape control treatments on seed yield and yield components (Pooled data 2015/2016 and 2016/2017 season)

Irrigation period	Broomrape control treatment	Plant height (cm)	Dry weight/plant (g)	No. of pods/plant	Weight of pods/plant (g)	100- seed weight (g)	Seeds yield (t/ha)
14 days	Glyphosate (6.35 g a.i./ha) twice at 35 and 56 days	77.90 a	43.10 a	41.04 a	91.30 a	33.12 a	6.74a
	Glyphosate (6.35 g a.i./ha) twice at 40 and 61 days	75.60 ab	41.75 a	39.59 a	88.92 ab	32.75 ab	6.24ab
	Glyphosate (5.29 g a.i./ha) twice at 35 and 56 days	75.34 ab	35.22 cd	34.14bc	85.99 b	31.60abc	5.06bcde
	Glyphosate (5.29 g a.i./ha) twice at 40 and 61 days	74.44 b	34.09cde	29.46efg	82.63 c	28.83cdefg	4.73bcdef
	Soil solar. F+ glyphosate (6.35 g a.i./ha) at 35 days	73.85 b	32.49 de	26.11ghijk	81.71 cd	28.00defgh	4.51bcdef
	Soil solar. + glyphosate (5.29 g a.i./ha) at 35 days	70.84 c	29.21fgh	23.71 kl	79.40cdef	26.31efghi	4.2def
	Soil solarization only	59.89 h	28.83gh	25.53ijk	72.72 h	18.99 j	3.24fgh
	Hand pulling (twice)	47.51i	22.25 j	25.84hijk	66.12 j	23.79ij	2.26ghi
	Control (un-treated.	36.25jk	8.84 l	13.35 n	19.21 m	18.12 k	1.46i
21 days	Glyphosate (6.35 g a.i./ha) twice at 35 and 56 days	69.50 cd	36.34bc	33.56bcd	86.61 b	31.88abc	6.07abc
	Glyphosate (6.35 g a.i./ha) twice at 40 and 61 days	68.34cde	33.28 de	30.81 def	82.60 c	30.81abcd	5.66abcd
	Glyphosate (5.29 g a.i./ha) twice at 35 and 56 days	67.81cde	32.17 def	31.97cde	81.45 cd	29.91abcde	4.90abcd
	Glyphosate (5.29 g a.i./ha) twice at 40 and 61 days	67.03 def	31.06efg	29.34efgh	79.04 def	29.80abcde	4.37cdef
	Soil solar. F+ glyphosate (6.35 g a.i./ha) at 35 days	66.27efg	29.23fgh	28.42fghi	78.52defg	28.53cdefg	4.08def
	Soil solar. + glyphosate (5.29 g a.i./ha) at 35 days	65.19efg	27.52 hi	26.46ghijk	74.08 h	25.58ghi	3.96def
	Soil solarization only	53.43 h	18.53 j	18.36 m	67.91ij	15.51 L	2.64fgh
	Hand pulling (twice)	45.50i	18.19 k	21.09Lm	53.29 k	21.81 j	2.16hi
	Control (un-treated.	34.48 k	7.52lm	11.37 n	16.77mn	16.64 kl	1.42i
28 days	Glyphosate (6.35 g a.i./ha) twice at 35 and 56 days	67.30 de	33.22 de	30.69 def	80.64cde	29.51bcdef	5.30abcde
	Glyphosate (6.35 g a.i./ha) twice at 40 and 61 days	65.10efg	31.53efg	28.32fghi	78.59defg	27.83defgh	5.02bcdef
	Glyphosate (5.29 g a.i./ha) twice at 35 and 56 days	63.97fg	28.80gh	27.78fghij	76.86fgh	26.66efghi	4.44cdef
	Glyphosate (5.29 g a.i./ha) twice at 40 and 61 days	63.91fg	27.58 hi	26.69ghijk	69.83i	26.17fghi	3.94def
	Soil solar. F+ glyphosate (6.35 g a.i./ha) at 35 days	57.40 h	26.82 hi	24.71jk	67.78ij	25.72ghi	3.80efg
	Soil solar. + glyphosate (5.29 g a.i./ha) at 35 days	59.84 h	24.77ij	21.24Lm	65.83 j	24.65hij	3.26fgh
	Soil solarization only	49.20i	13.10jk	15.51 n	65.62 j	14.56 kl	2.26ghi
	Hand pulling (twice)	39.00 j	15.53 k	19.16 m	47.83 L	18.03 k	1.73hi
	Control (un-treated.	29.92 L	5.55 m	7.82 o	15.13n	14.03 L	1.2i

Soil Solar. F = Soil solarization in months (August, September, and October). Significantly ($p < 0.005$)

carried out using Duncan's multiple range test (DMRT) at 5% probability level. Bartle test of homogeneity for error indicated that the variance of data of both seasons was insignificant. Thus, the combined analysis was carried out.

RESULTS AND DISCUSSION

Effect of irrigation periods and broomrape control treatments on broomrape: Results of Table 1 showed that shortening irrigation interval decreased all of the broomrape growth attributes. These decreases may be due to steroids that are secreted by the roots of pea due to excessive water of irrigation. The obtained data in this study are in agreement with results obtained by Nasser and Mekky (2002) and Fakkar *et al.* (2016).

All broomrape control treatments significantly ($P < 0.005$) decreased broomrape growth. The results may be caused by stimulants secreted by the roots at a certain stage of host development, a stage before or during flowering causing infusion of broomrape and attachments to the host. Nasser and Mekky (2002) found that the germination of *Orobancha crenata* seeds require a definite substance produced by the host *Vicia faba*. This stimulant is mostly secreted by the

roots just before or during flowering. The results are in agreement with those of El-Metwally *et al.* (2013).

Yield and its components: Results recorded in Table 2 showed that shortening irrigation periods significantly increased yield and its components in both the seasons. These results are consistent with those of Nasser and Mekky (2002). Seed yield increased by all glyphosate treatments, the highest increase was obtained by glyphosate treatment application at rate of 6.35 g a.i./ha, applied twice as compared to control treatment. This increase in seed yield may be because of decrease in the number and fresh weight of broomrape spikes. These results are in agreement with those of Nasser and Mekky (2002).

Interaction between irrigation periods and broomrape control treatments on broomrape: Results outlined in Table 3 showed that broomrape growth was significantly affected by the interaction between irrigation periods at interval of 21 days and broomrape control treatments. All interaction treatments between irrigation periods and glyphosate treatments resulted in high reduction in percentage of broomrape growth as compared to irrigation for 28 days and control treatment. Similar trends were achieved by Nasser

Table 5 Residue of glyphosate in pea seeds at 6.35 g a.i./ha after 60 days of sowing

Irrigation period	Residual (ppm)	Maximum residual level (MRL), ppm*
14 days	0.052	2.0
21 days	0.055	
28 days	0.018	
Hand pulling	Not detected	

*Codex of pesticide maximum residual level in UK (2016)

and Mekky (2002) who reported that interaction analysis showed a significant decrease in number and dry weight of broomrape spikes.

Yield and its components: Results in Table 4 illustrated that all the interaction between irrigation periods and broomrape control treatments were highly significant for all pea characters in the two seasons. The interaction between irrigation for 14 days interval and the first treatment of glyphosate at a rate of 6.35 led to highest pea characters. The lowest value was obtained from the interaction between irrigation for 28 days periods and control treatment. These results are in harmony with those obtained by El-Metwally (2013) and Nasser and Mekky (2002).

Herbicide residues: Results in Table 5 show that glyphosate residue levels in pea seeds at harvest in all cases were below the established MRL of UK standard (2.0 ppm). The results obtained were also supported by Balinova and Lalova (1992) who demonstrated that the herbicide was translocated rapidly from the leaves to the roots but it accumulates in the leaves and multiplied ten times higher than in the root, while seeds did not accumulate any traces of the active compounds or its main metabolites.

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