Middle East Journal of Agriculture Research
ISSN 2077-4605

Volume : 04 | Issue : 02 | April-June | 2015
Pages: 240-249

Determination of the Critical Period for Weed Control on Potato (*Solanum tuberosum*, L.) Crop

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ABSTRACT

Two field experiments were carried out during 2011/12 and 2012/13 winter seasons at the Experimental Farm, of Sakha Agriculture Research Station, Agriculture Research Centre, Kafr El-sheikh Governorate, Egypt clay soil. The experiments were conducted to study the effect of weed competition on growth, yield and yield components of potato; as well as, to determine the critical period for weed control (CPWC) in potatoes. Each experiment comprised twelve treatments, divided into two groups. Each group contained of six treatments. The first group consisted of six weed free treatments from potato planting for different durations as follow; weed free for the whole season and weed free only for 3, 5, 7, 9 and 11 weeks from planting. The second group consisted of six weed competition period treatments from potato planting for different durations as follows; weed competition for the whole season and weed competition only for 3, 5, 7, 9 and 11 weeks from planting. The main findings of this work showed that the effect of weed competition on potato tuber yield started about 15 days after planting and continued until about 70 days after planting. At this period (10 weeks from planting), The effect of the weed competition to potato plants reached its maximum effect on the studied characters; i.e., average number of tubers per plant, average tuber weight, number of tubers/10 kg, plant height (cm), average number of main stems / plant, tuber grading index, tuber shape index, tuber dry matter %, starch %, and tuber specific gravity all these characters were decreased. Weed competition for the whole season reduced the potato yield by 61.4% and 74% under 10.250 and 2.05 kg/m^2 of total fresh weight of weeds in 2011/12 and 2012/13 winter seasons respectively. The beginning and the end of the critical period of weed control in potato CPWC was based on 10% tuber yield loss. The onset period of the CPWC started from 2 weeks after planting. The end of the CPWC was at10 weeks after planting. So, under these conditions of this study, the obtained results showed that weed control strategies in potato planting should be during this period (2 WAP until 10 WAP).

Key words: potato, *Solanum tuberosum*, L., critical period, weed control, weed competition.

Introduction

Potato (*solanum tuberosum*, L.) belongs to family *Solanaceae;* as one of the most important vegetable crops for local consumption, processing and exportation in Egypt. The whole cultivated area in Egypt 381379 fed. produced 4265178 tons, by average 11.18 ton/ faddan in Egypt in 2013 all seasons .Weeds in Potato fields not only compete with potato for growth factors, but also act as hosts of insects and fungal diseases that inturn infest potato plants. Weed growth reduce the yield of potato tuber by 50 % as reported by Vincent, (2009) and can even weed control in a timely manner before they cause a lack of growth in the crop by crop plants compete for light and space and food, and the critical period must determine for weed competition for crop plants. Weed competition before or after the critical periods remember effects on crop yields.So the crop is vulnerable to weed competition and no single method enough by itself for avoiding it, though the period of weed competition controlling weeds based on critical period for weed control (CPWC) is the most appropriate way to optimize weed control applications. Mondani, *et al*. (2011) found that weeds reduced potato yield by 54.8 %. Their results illustrated that the beginning and the end of CPWC in potato was based on 5% and 10% tuber yield loss level corresponding to 11 and 19 days after crop emergence, respectively. The end of the CPWC was based on 5% and 10% yield loss level corresponding to 65 and 51 days after crop emergence, respectively.
This study was conducted to determine the beginning and the end of critical periods of weed competition of potato crop to avoid potato yield losses due to weed competition.

Materials and methods:

A local certified Spunta seed potato tubers was planted during the two successive winter seasons of 2011/2012 and 2012/2013. The experiment was conducted at Sakha Agricultural Research Station, Kafr El-

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Sheikh Governorate clay soil. The planting was done on October 23rd 2011 and 25Th 2012. The experimental unit consisted of five rows, 0.7 m wide and 6.00 m long, making an area of 21 m^2. The hills were at 25 cm apart. Each plot contained 120 whole tubers. Harvesting was accomplished 120 days after planting. All the agricultural practices for potato production were carried out as common in this area.

Treatments:

Each experiment included twelve treatments which categorized into two groups as follows: the first group consisted of six treatments of weed removal; i.e., weed free for the whole season by hand weeding, free for 3, 5, 7, 9 and 11 weeks from planting. The second group consisted of six treatments of weed competition; i.e., weed competition for the whole season, for 3, 5, 7, 9, and 11 weeks from planting. With these two types of treatments, both the critical weed-free requirement and the critical duration for weed competition were determined. The schemes of the critical period of weed competition to potato were designed according to (Dawson, 1970).

Measurements:

Weed characters:

Weeds were hand pulled at random broad-leaved weeds, from one square meter in each plot at 11weeks after planting (WAP). Weeds were identified into species and classified to annual broad-leaved weeds, narrow-leaved and total weeds. The fresh weights of each species were determined as (g/m^2). Observations were recorded on ten randomly selected plants per plot in each replication.

Vegetative growth and yield parameters:

Ten whole plant samples per plot were randomly used, 100 days after planting, for the determination of the vegetative growth (plant height (cm), number of main stems and total chlorophyll percentage (mg/100g F-W) It was determined using the fourth top leaves after 80 and 100 days from planting according to Wettstein, (1957) method. Chlorophyll (a) $mg/100g=10.3(O.D)_{663} - 0.918(O.D)_{644}$ and chlorophyll (b) $mg/100g=19.7(O.D)_{644} - 3.87(O.D)_{663}$). A random ten hills were used to calculate the average tuber weight (g), average tuber number. Number of tubers per ten Kg was determined using a random sample of 10 Kg of tubers from each treatment and then counted. The accepted category to potato processing is that count 72-112 tubers in such treatment (Frito Lay Company, 1999). Tuber yield (ton/Fed.) was recorded as the total weight of all harvested tubers per plot and converted into tons per feddan.

Physical characteristics:

Random samples 0f 10 tubers per treatment were randomly used to measure the physical characteristics of the tubers; tuber length and diameter were measured to calculate the tuber shape index by dividing the length by the width; as reported by Winigar and Ludwing (1974). Tuber specific gravity was determined by weighting a certain weight of tubers for each treatment, then the specific gravity was computed according to the following equation:-

Tuber specific gravity = Tuber's weight in air / (Tuber's weight in air - Tuber's weight in water); as described by Dinesh, *et al*. (2005). Tuber grading index was computed as follows; potatoes were graded into three categories according to its size i.e., large size (more than 60 mm), medium size (40-60 mm) and small size (28-40mm). Tuber grading index = 1× weight of small size) + (2× weight of medium size) + (3× weight of large size).

Tuber quality:

Random samples of 10 tubers per treatment for each replicate were randomly used to determine the following tuber quality characters:

1- Tuber dry matter %: Was carried out by weighing a certain weight of fresh tubers and then dried. Dry matter % = Dry weight / Fresh weight × 100 (Haase, 2003).

2- Determination of starch %: Tuber starch percentage (%) was determined using a sample of 1 g of dry weight of tuber, according to the method described in A.O.A.C. (1970).

Experimental design and statistical analysis:

The used experimental layout was arranged in a randomized complete blocks design (R.C.B.D), with four replicates. Twelve treatments of weed control were applied.The collected data of the experiments were statistically analyzed according to the procedures outlined by Gomez and Gomez (1984). The mean values of the tested treatments were compared by least significant range (L.S.R.) according to Duncan's Multiple range test (1955) at $p = 0.05$ level of significance. The relative and actual yield were subjected to analysis of variance using regression curve, estimation function to analysis of statistical producers for social sciences (SPSS 16.0 for

windows), to evaluate the effect of the length of the weed-free periods and the duration of weed competition on relative potato yields according to Knezevic *et al*., (2002), Evans *et al*., (2003) and Norsworthy and Oliveria, (2004). Three response curve models namely; linear quadratic and logistic equation were fitted to study the relationships between potato yield / Fed. and duration of weed-free and /or weed-competition period (Neter *et al*.,1990; Hall *et al*., 1992 and Cousen, 1991 and Knezevic *et al*., 2002).

Results and Discussion

Weed characters:

Fresh weight of broadleaved weeds (g/m^2):

The results shown in Table (1) appeared that the fresh weight of broad-leafed weeds were significantly affected by various weed free and weed competition periods as compared with untreated check (weed competition for the whole season). The highest fresh weight of weeds was observed from weed competition treatment for the whole season followed by weed competition for 11 weeks after planting (WAP) and weed-free for 3 WAP for the both seasons of this study. The lowest weeds fresh weight were observed with weed-free for the whole season, weed-free for 11 WAP and weed competition for 3 weeks after planting treatments in the two seasons. It could be concluded that weed-free treatments up to 7 and 9 WAP gave nearly full control of weeds in potato fields throughout the two growing seasons. These results are in general agreement with those reported by Jones *et al*. (2007) who found that the greatest emergence of annual broadleaf weeds were observed in the period from potato planting until flowering. Karimmojeni, *et al*., (2013) and Pamela, *et al*., (2014) found that weeds must be controlled during the first three weeks of the crop's growing season.

Fresh weight of grassy weeds (g/m^2):

Data presented in Table (1) indicated that the highest fresh weight of grassy weeds were observed with weeds competition treatment when extended for the whole season followed by weed competition for 11 WAP and weed-free for only 3 WAP for both seasons. The lowest fresh weight were observed from weed-free for the whole season, weed free for 11 WAP and weed competition for only 3 WAP treatments in the two seasons. It could be concluded that weed-freeplots up to 9, 7 and 5 WAP gave nearly full control of grassy weeds in potato fields throughout the two growing seasons. These results are in general agreement with those reported by Jones, *et al*. (2007), Karimmojeni, *et al*. (2013) and Pamela, *et al.* (2014), as they found that weeds must be controlled during the first 3 weeks of the crop's growing season. Such an approach would keep yield loss levels below 5%.

Fresh weight of total weeds (g/m^2):

The same trend as fresh weight of broadleaved weeds and grassy weeds results in Table (1) showed that the highest fresh weights were obtained for total weeds from weed competition for the whole season followed by weed competition for 11 WAP and weed-free for only3 WAP for both seasons. On the other hand, the lowest values of fresh weight weeds were observed from weed-free plots during the whole season and weed competition for only 3 WAP in the two seasons. It could be concluded that weed-free for 5, 7 and 9 WAP gave nearly full control of weeds, in potato fields throughout the growing season, in the two plantations.

Table 1: Effect of weed competition treatments on fresh weight of broad-leaved, grasses and total weeds (g/m2) in potato fields in Sakha, during 2011/12 and 2012/13 winter seasons.

Treatments	2011/12 After (11 weeks)			2012/13 After (11 weeks)		
	Broadleaf weeds	Grassy weeds	Total	Broadleaf weeds	Grassy weeds	Total
Weed free for the whole season.	0.95 g	1.01 d	1.96	0.2 g	0.2 d	0.4 e
Weed free only for 3 WAP.	2310 b	1330.5 c	3640.5 c	462 b	266.1 c	728.1 c
Weed free for only 5 WAP.	560.45 d	353.76 d	914.21 d	112.1 d	70.8 d	182.9 d
Weed free for only 7 WAP.	92.49 e	123.54 d	216.03 e	18.5 e	24.7 d	43.2 e
Weed free for only 9 WAP.	54.67 f	51.53 d	106.2 e	10.9 f	10.3 d	21.2 e
Weed free for only 11 WAP.	0.81 g	1.02 d	1.83 e	0.2 g	0.2 d	0.4 e
Weed competition for whole season.	3920.25 a	6330.5 a	784.1 a	1266.1	2050.2a	
Weed competition only for 3 WAP.	6.04 g	31.32 d	37.36 e	1.2 g	6.3 d	7.4 e
Weed competition for only 5 WAP.	0 g	0 d	0 e	0 g	0 d	0 e
Weed competition for only 7 WAP.	0 g	0 d	0 e	0 g	0 d	0 e
Weed competition for only 9 WAP.	0 g	0 d	0 e	0 g	0 d	0 e
Weed competition for only 11 WAP.	1926.15 c	4123.5 b	385.23 c	824.7 b	1209.9	

(WAP):Weeks after planting

These results are accepted with those reported by Abusteit and Shehata (1993), Ahmadvand, *et al*. (2009) and Mondani, *et al*. (2011) as they found that weeds reduced potato yield by 54.8 %. Their results illustrated that the beginning and the end of the critical period of weed control in potato (CPWC) was based on

5% and 10% tuber yield loss level corresponding to 11 and 19 days after crop emergence. The end of the CPWC was based on 5% and 10% yield loss level corresponding to 65 and 51 days after crop emergence.

Effect of weed competition treatments on potato vegetative characters:

Plant height (cm):

Plant height tended to be increased with increasing weed free period and vice versa with weed competition periods where it tended to decrease with increasing competition periods (Table, 2). The highest reduction in plant height obtained from weed free plots for the whole season than weed competition periods for the whole season in 2011/12&2012/13 winter seasons. The lowest values in plant height were obtained from weed competition for the whole season, 7 and 11WAP in both seasons of this study.

Number of main stems / plant:

The best treatments which led to the increase in the number of main stems/plant were weed free for the whole season, weed free for 7, 9 and 11 WAP and weed competition for only 3 WAPin 2011/12 winter season as compared with weed competition for the whole season which gave only one stem / plant (Table, 2). The lowest number of main stems obtained from weed competition for the whole season and it did not significantly differ from weed competition for 9 and 11WAP treatments in 2011/12 and 2012/2013 seasons. In general it was found that delaying weed control up to 5 WAP decreased the number of stems per plant significantly. These results are in the same trend with those reported by Levett (1992) and Ciuberkis, *et al.* (2007) which they indicated that weed competition decreased dry matter accumulation, leaf area index, crop growth rate, light absorption, light extinction coefficient and radiation use efficiency of potato.

Table 2: Effect of weed competition treatments on potato growth characters and leaves chl. content in Sakha2011/12 and 2012/13 winter seasons.

Treatments	2011/12				2012/13			
	Plant height (cm)	Number of main stems / plant	Total chlorophyll		Plant height (cm)	Number of main stems / plant	Total chlorophyll	
			Total chl. 80 days	Total chl. 100 days			Total chl. 80 days	Total chl. 100 days
Weed free for the whole season.	37.8 a	2.5 a	5.82 a	6.17 a	37.3 a	3.3 a	5.72 a	4.23 a
Weed free only for 3 WAP	20.5 de	1.5 bcd	5.30 abc	4.44 b	25.8 d	1.5 cde	4.80 c	2.59 g
Weed free for only 5 WAP.	21.8 cde	1.8 abcd	5.41 ab	4.86 ab	28.5 c	2 bc	5.23 b	2.87 d
Weed free for only 7 WAP.	21.8 cde	2 abc	5.47 a	4.87 ab	30 c	2 bc	5.24 b	3 c
Weed free for only 9 WAP.	23.8 b	2.3 ab	5.63 a	5 ab	33.8 b	3a	5.54 a	3.20 b
Weed free for only 11 WAP.	37 a	2.3 ab	5.66 a	5.16 ab	36.8 a	3.3 a	5.67 a	4.18 a
Weed competition for whole season.	20 e	1 d	3.70 c	2.83 c	22.8 e	1 e	3.7 f	2.24 j
Weed competition only for 3 WAP.	36 a	2 abc	5.31 abc	4.67 ab	32.8 b	2.3 b	5.04 b	2.77 e
Weed competition for only 5 WAP.	22.8 bc	2 abc	4.7 abc	4.59 b	28.8 c	1.8 bcd	4.35 d	2.69 f
Weed competition for only7 WAP.	22.bcd	1.5 bcd	4.65 abc	4.17 bc	24 de	1.5 cde	3.96 e	2.46 h
Weed competition for only 9 WAP.	21.3 cde	1.5 bcd	4.32 abc	4.17 bc	23.5 de	1.3 de	3.85 ef	2.36 i
Weed competition for only 11 WAP.	20.5 de	1.3 cd	3.78 bc	3.94 bc	23e	1 e	3.7 f	2.24j

(WAP):Weeks after planting. DAP = Days after planting

Total chlorophyll (a + b) pigments in potatoes leaves after 80, 100 days from planting:

Table (2) showed that total chlorophyll (a + b)% in potato leaves at 80 and 100 days from planting were affected significantly at 5% level of significance by various treatments of weed free and weed competition periods in 2011/12 and 2012/13 winter season. The highest concentration of total chl. after 80 and 100 days from planting produced from allowing weeds free for the whole season compared with weed competition for the whole season in 2011/12 and 2012/13 winter seasons.

Data in Table (2) illustrated that total chl. after 80 and 100 days from planting was affected significantly between weed free periods and weed competition, The highest chlorophyll percentage recorded from weed free treatments for the whole season, weed free for 11, 9, 7 and weed competition for 5 WAP compared with weed competition for the whole season in 2011/12 and 2012/13 winter seasons. These results are in the same trend with those reported by Ciuberkis, *et al.*. (2007) which they indicated that weed competition decreased crop growth rate, light absorption, light extinction coefficient and radiation use efficiency of potato plants. Accordingly the chlorophyll content of the pants may be reduced also by weeds shading of the potato plants.

Effect of weed competition treatments on potato yield and yield component:

Average number of potato tubers / plant:

Data in Tables (3) showed that average number of tubers/plant responded significantly to both weed free and weed competition periods in the two seasons. The highest number of potato tubers/plant were found with weed free plots for the whole season, weed free for 11and 9 WAP. The lowest number of tubers / plant was

obtained from weed competition for the whole season and it did not significantly differ from weed competition for 9 and 11 WAP in both seasons of the study. In general it was found that delaying weed control up to 5 WAP decreased the number of tubers per plant significantly. These results are similar to those reported by David and George (1990) as they indicated that delaying the removal of green foxtail for 2 weeks after crop emergence reduced the number of potato tubers per plant. They added also that the proportion of unmarketable tubers increased as the duration of weed competition increased.

Table 3: Effect of weed competition treatments on potato yield and yield components in Sakha, 2011/2012 and 2012/2013 winter seasons.

Treatments	2011/12				2012/13			
	Number of tuber / plant	weight Tuber average (g)	Number of tuber /10 kg.	Yield ton / fed.	Number of tuber / plant	Tuber average weight (g)	Number of tuber /10 kg.	Yield ton / fed.
Weed free for the whole season.	10a	91.1 a	97.5 a	10.68 a	11a	114.2 a	110.3 a	12.7 a
Weed free only for 3 WAP	5e	63.7 f	61 f	5.2 fg	4.8 c	90.5 fg	90 d	6.5 f
Weed free for only 5 WAP.	6.5cd	74.6 d	71.5 d	6.94 d	8 b	108.4 c	94.8 c	8.2 e
Weed free for only 7 WAP.	8.5b	83.4 c	85.3 c	6.79 de	8.3 b	110.6bc	95.8 c	9.1 d
Weed free for only 9 WAP.	9.3ab	90.9 a	90.3 b	8.70 c	8.8 b	112.1ab	103 b	11.8 b
Weed free for only 11WAP.	10a	90.5 a	97.3 a	10.1 ab	10a	113 ab	109.8a	12.4 a
Weed competition for whole season.	5e	61.1 g	50.5 g	4.12 g	2.8 d	86 h	72 f	3.3 i
Weed competition only for 3 WAP.	9ab	87.3 b	89.8 b	8.91 bc	8.3 b	104.2 d	102.3b	10.5 c
Weed competition for only 5 WAP.	6.8cd	72.2 e	69.3 e	6.8 de	5.5 c	91.2 f	88.3 d	6.2 f
Weed competition for only7 WAP.	7.3c	71.7 e	69.3 e	5.49 efg	5 c	95 e	81.5 e	4.9 g
Weed competition for only 9 WAP.	5.8de	62.9 fg	49.8 g	5.62 def	4.5 c	95.8 e	81.3 e	4.2 h
Weed competition for only 11 WAP.	5e	61.9 fg	49.5 g	4.54 fg	4.5 c	87.3 gh	70.8 f	3.3 i

Values with the same Alphabetical letter, in a comparable group of means don't differ significantly from each other according to Duncan's Multiple Range best at 0.05 level of significance.
DAP = Days after planting. (WAP):Weeks after planting

Average tuber weight (g):

Results in Table (3) showed that average weight of potato tubers was affected positively and significantly by removal of weeds up to 7 WAP and did not significantly differ from the treatments of weed free for 7, 9 and 11 and for the whole season and as well weed competition for 3WAP in the two seasons of this study. Allowing weeds to compete with potato plants for 5, 7, 9 and 11 WAP and for the whole season and weed-free for 3 and 5 WAP significantly decreased the average tuber weight. Data in Table (3) also showed that weed-free for the whole season treatment gave the highest tuber weight in the two seasons. Meanwhile, the lowest values for the average tuber weight per plant were obtained from weed competition for the whole season. These results are in accordance with those obtained by Levett, (1992), where he found that the critical period for weed competition began at 14 days after planting and continued up to 56 DAP. Hand weeding 28-42 DAP appeared to adversely affect tuber initiation due to mechanical root disturbance, while regular hand weeding after 56 days tended to reduce yields, probably as a result of disturbance of the vine canopy.

Number of tubers per 10 Kg:

Generally the accepted category of tubers (72-112 tubers/10 Kg) was issued by Frito Lay Company (1999) suggesting that when the number /10 Kg was less than 72 tubers/10 Kg, the large tubers may have the hallow heart physiological disease, which rewind the end product potato chips. Number of tubers more than 112 ones /10 Kg produces small slices which decreases the quality of the end product. Results in Table (3) showed that the largest number of tubers per 10 Kg although it were in the accepted range of tubers numbers (72-112) was obtained from the weed free plots for the whole season and weed free for 9 and11 WAP while the lowest number was that of weed competition for the whole season and weed competition for 7, 9 and11 WAP in 2011/12 winter season which are rejected due to the small slides. On the other hand the largest number of tuber in the second season was obtained from weed free plots for the whole season and weed free for 11 WAP.The smaller numbers were obtained from weed competition for the whole season and. Which produce rejected tubers according to Frito Lay (1999).

Tuber yield (ton / feddan):

Data presented in Table (3) appeared that The highest tuber yield per feddan was obtained from weed free for the whole season, weed free for 11 and 9 WAP and weed competition for only 3 WAP in the two seasons compared with weed competition treatment for the whole season in both experiments. The increases in tuber yield of potato per feddan, under various weed early or late removal treatments in both season, than untreated check competition for the whole season was attributed to the increases in number of tuber / plant; average tuber weight increasing in tuber grading index. These results may also owing to increases in chl.(a & b

)contents in potato leaves and consequently the increase in assimilates as total carbohydrate stored in tubers which resulted from minimizing the weed competition to potato plants. These results are in accordance with those reported by Abusteit and Shehata (1993), Ahmadvand, *et al.*, (2009) and Mondani, *et al.,* (2011) as they found that weeds reduced potato yield by 54.8 %.

Effect of weed competition treatments on potato quality:

Tuber grading index:

This trait give an impression about prevailing size of the tuber in a given lot of potatoes, the large index proves prevailing of the large tubers and vise versa. Table (4) showed that weed free treatments for the whole season weed free for 11 and 9 and weed competition for 3 WAP increased tuber grading index as compared with weed competition for the whole season.

Tuber shape index:

Table (4) illustrates that the tuber (oval to long) resulted from weed free plots for the whole season was recorded 1.7; this means that Spunta shape was unchanged. The rest of treatments, there were no much significant difference among them compared with weed competition for the whole season which gave 1.3 (round to oval) in 2011/12 winter season. This means that the presence of weed for the whole growing season may alter the Spunta tuber shape from long oval to round oval.While the results in 2012/13 winter season showed that, there are significant differences between weed free and weed competition where weed free for the whole season, weed free for 11, 9 and 7 WAP gave 2.14, 2.12, 2.08 and 2.08 compared with the weed competition for the whole season which gave round tubers.

Tuber dry matter (%):

All weed free period treatments increased the tuber dry matter percentage as appears in Table (4) in both seasons as compared with weed competition treatments for the whole seasons. The highest significantly dry matter was obtained by weed free for the whole season, weed free for 11and 9 WAP and weed competition for 3 WAP compared with weed competition for the whole season during the two years of this study. These results are in accordance with those obtained by Baziramakenga and Leroux (1994) and Ciuberkis, *et al.* (2007) as they indicated that, the critical weed-free period, when weed competition was detrimental to yield, started from planting until 25 days after flowering. The weed competition decreased dry matter accumulation in potato tuber.

Table 4: Effect of weed competition treatments on potato tuber characteristics in Sakha station, 2011/12 and 2012/13 winter seasons.

Treatments	2011/2012					2012/2013				
	Tuber grading index	Tuber shape index	Tuber dry matter (%)	Tuber starch (%)	Tuber specific gravity	Tuber grading index	Tuber shape index	Tuber dry matter (%)	Tuber starch (%)	Tuber specific gravity
Weed free for the whole season.	23.15 a	1.7 a	22.5 a	83.75 a	1.048 a	25.56 a	2.14 a	22.4 a	86.5 a	1.072 a
Weed free only for 3 WAP.	10.15 de	1.4 ab	17.5 bc	62.75 d	1.01 cd	14.4 d	1.62 c	17.07 bc	75.5 de	1.002 e
Weed free for only 5 WAP.	14.05 c	1.5 ab	18.5 b	70.25 c	1.013 bc	18.81 c	1.86 b	18.51 b	78.25 c	1.01 d
Weed free for only 7 WAP.	14.6 c	1.5 ab	18.6 b	75 b	1.035 a	20.13 b	2.08 a	18.49 b	76.65 d	1.035 c
Weed free for only 9 WAP.	18.9 b	1.6 ab	20.9 a	81.5 a	1.043 a	24.81 a	2.08 a	20.4 ab	84 b	1.053 b
Weed free for only 11 WAP.	22.45 a	1.7 ab	21.5 a	83.25 a	1.035 a	25 a	2.12 a	21.25 a	85.35 ab	1.047 bc
Weed competition For the whole season.	7.925 f	1.3 b	17.3 c	61.5 d	1.01 c	7.68 gh	1.08 e	17.2.c	71.37 f	1.01 d
Weed competition only for. 3 WAP.	19.45 b	1.6 ab	20.9 a	80.75 a	1.015 b	20.82 b	1.98 ab	20.25 ab	85.72 a	1.057 b
Weed competition for only 5 WAP.	14.45 c	1.5 ab	17.7 c	68.75 c	1.005d	11.25 e	1.34 d	17.04 c	75.62 de	1.035 c
Weed competition for only 7 WAP.	10.97 de	1.4 ab	17.3 c	64.5 d	1.01c	9.37 f	1.25 d	17.97 bc	74.9 e	1.015 d
Weed competition for only 9 WAP.	11.55 d	1.3 b	17.4 c	61.75 d	1.01c	8.94 fg	1.23 d	17.53 bc	74.57 e	1.015 d
Weed competition for only11 WAP.	8.97 ef	1.3 b	17.0 d	61.75 d	1.01c	7.5 h	1.07 f	17.0 d	70.25 f	1.01 d

Values with the same Alphabetical letter, in a comparable group of means don't differ significantly from each other according to Duncan's Multiple Range best at 0.05 level of significance.
(WAP):Weeks after planting

Starch (%):

There are significant differences between weed free and weed competition treatments, in starch % in tuber dry natter at harvest in both seasons as shown in the Table (4). the highest increases in starch % were obtained from weed free plots for the whole season, weed competition for only 3 WAP, weed free for 11 and 9 WAP compared with weed competition for the whole season in 2011/12 winter season, whilst in 2012/13 winter season, weed free for whole season, weed free for 11 and 9 WAP and weed competition for 3 WAP gave increases in the starch percentage compared with weed competition for the whole season. This result may be attributed to the decreases in total chlorophyll (a + b) activeness. These results are in agreement with those obtained by Ciuberkis, *et al.* (2007), as they indicated that, the critical weed-free period, when weed competition was detrimental to yield, started from planting until 25 days after flowering. The weed competition decreased crop growth rate, light absorption, light extinction coefficient and radiation use efficiency of potato. Such situation may reduce photosynthates and in turn reduces starch accumulation in the tubers.

Tuber specific gravity:

The result in Table (4) illustrated that the best tuber specific gravity was that obtained from plots that weed free for the whole season, weed free for 9 WAP and weed competition for only 3 WAP. The highest specific gravity were that of the weed free plots for the whole season, weed free for 9, 11 and 7 WAP and weed competition for only 3 WAP compared with weed competition for the whole season. These results are in in the same trend with those obtained by Ciuberkis, *et al.* (2007) as they stated also weed competition decreased crop growth rate, light absorption, light extinction coefficient and radiation use efficiency of potato.

Critical period determination for weed control in potato:

The relationship between potato tuber yields per feddan and the duration of both weed competition and weed free periods in 2011/12, 2012/13 was used to determine the critical period of weed control in potato crop by using biological crop curves or regression approaches (Table, 5). Calculation of the critical period of weed competition (CPWC) was based on 10% acceptable yield loss level used to recognize both the beginning and end of the critical period. CPWC began at 2 WAS in the two seasons, the end of CPWC was at 10 WAP in both seasons of the study, based on 10% acceptable yield loss and this results of the research Table (5) and Figure (1) suggesting that weed control in potato crop must be in this period. The potato fields should be kept weed free until 10 WAP in order to prevent yield loss in excess of 10% of yield loss. Weeds that emerged after that period would grow in a competitive disadvantage with potato Table (5) and Figure (1).

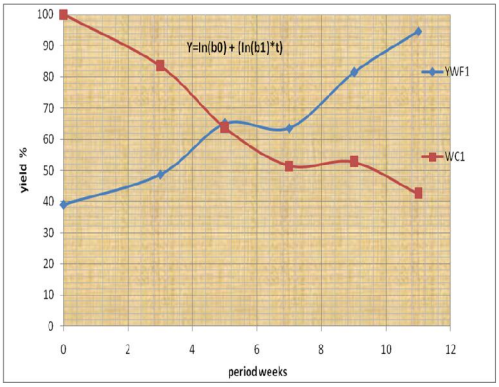
Biological crop curve:

The data of Table (5);Generally, appeared that the yield losses in early competition period increased with increasing the time of weed competition; whereas in weed free period treatments the yield losses was decreased as the time of weed free increased.

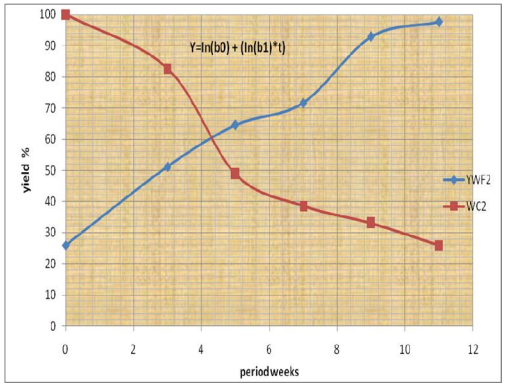
Table 5: Potato yield increases % of treated plot as compared with weed competition for the whole season in 2011/12 and 2012/13 winter seasons.

Treatments	2011/12		2012/13	
Weed removal or competition treatment	Yield/feddan	Yield loss%	Yield/feddan	Yield loss%
Weed free only for 3 WAP.	5.2 fg	51.31	6.5 f	48.82
Weed free for only 5 WAP.	6.94 d	35.02	8.2 e	35.43
Weed free for only 7 WAP.	6.79 de	36.42	9.1 d	28.35
Weed free for only 9 WAP.	8.70 c	18.54	11.8 b	7.09
Weed free for only 11 WAP.	10.1 ab	5.43	12.4 a	2.36
Weed competition for whole season.	4.12 g	61.42	3.3 i	74.02
Weed competition only for 3 WAP.	8.91 bc	16.57	10.5 c	17.32
Weed competition for only 5 WAP.	6.8 de	36.33	6.2 f	51.18
Weed competition for only 7 WAP.	5.49 efg	48.60	4.9 g	61.42
Weed competition for only 9 WAP.	5.62 def	47.38	4.2 h	66.93
Weed competition for only11 WAP.	4.54 fg	57.49	3.3 i	74.02

Values with the same Alphabetical letter, in a comparable group of means don't differ significantly from each other according to Duncan's Multiple Range best at 0.05 level of significance.
(WAP): Weeks after planting



YWF1=Yield of weed free in 2011/12 season
YWC1=Yield of weed competition in 2011/12 season



YWF2=Yield of weed free in 2012/13 season
YWC2=Yield of weed competition in 2012/13 season

Fig. 1: Potato tuber yield response to increasing periods of weed free and weed competition in 2011/12 and 2012/13winter season.

This increasing in tuber yield (ton / feddan) trait under that competition period may be attributed to the positive effects of early removal weeds on growth which occurred as a result of the less competition between potato and

weed plants for the limited environmental resources such as (light, water and nutrients) on which plant growth was dependent up. These results are in accordance with those reported by Abusteit and Shehata (1993), Ahmadvand, *et al.*, (2009) and Mondani, *et al.,* (2011) as they found that weeds reduced potato yield by 54.8 %.

Regression approach (mathematical models):

For modeling the relationship between potato tuber yield and weed free or weed competition period in this study the above mentioned models were tested, Table (6) showed that the relationship between potato tuber yield as (ton/feddan) and weed free and weed competition Anova were statistically significant in both 2011/12, 2012/13winter seasons.

Table 6: ANOVA tables to quadratic model.

Relationship	Anova table to logistic model									
	2011/12 winter season					2012/13 winter season				
	Sum of Squares	Df	Mean Square	F	Sig	Sum of Squares	Df	Mean Square	F	Sig
Weed-free period										
Regression	93.2	2	46.6	37.4	.000	178.1	2	89	96.3	.000
Residual	26.2	21	1.2			19.4	21	0.9		
Total	119.4	23				197.5	23			
Weed-infestation period										
Regression	106.8	2	53.4	70.5	.000	58.6	2	29.3	143.5	.000
Residual	15.9	22	0.8			4.3	21	0.2		
Total	122.7	23				62.9	23			

It was clear that the suitable model which fitted for prediction yield losses or increases in potato tuber yield/feddan was quadratic equation because the correlation coefficient (R^2) was big than linear model and big standard estimate error (SE) which were smaller than those of the polynomial models were: Ý= ln (bo) + (ln (bi)*t) in potato tuber yield 2011/12 and 2012/13winter season (t/feddan). According to Singh *et al.* (1996) the relationship between crop yield (Y) and duration of weed-free or weed-competition period (×) by linear function: ỹ= a + b X ;where the parameters ỹ = the expected yield, a and b represent intercept and slope of regression of yield on the duration, respectively, or by the quadratic function: ỹ = a + b X + c X^2 where the parameters b and c represent intercept and slope of regression of yield on the duration, and logistic function : ỹ =ln (bo)+(ln (bi)*t) where the parameters b, c and d represent intercept and slope of regression of yield on the duration, and logistic function were used to estimate the critical period of weed competition to potato. Depending on these results the expected potato tuber yield t/feddan under different times of weed free and weed competition period in potato to maintain of 90% potato tuber yield t/feddan should be allowed weeds to competition not exceed 2 weeks after planting and the situation of the late duration of weed free period should be kept at least weed removed 10 weeks after planting (Tables, 7 and 8)

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Table 7: Parameters of the three studied models of the effect of weed free or weed competition periods on yield of potato (ton /feddan) in 2011/12 and 2012/13 winter seasons.

Weed competition Weed-free	Models	Constant	R2	SE	Prediction equation
2011/12					
Weed-free	Linear	3.863	0.771***	1.114	Y= a + b x
	Logistic	0.239	0.841***	0.132	Y= ln (bo)+(in(bi)*t)
	Quadratic	4.160	0.781***	1.117	Y= a + b x - cx2
Weed competition	Linear	3.863	0.839***	0.949	Y= a + b x
	Logistic	0.095	0.886***	0.107	Y= ln (bo)+(in(bi)*t)
	Quadratic	10.847	0.870***	0.870	Y= a + b x - cx2
2012/13					
Weed-free	Linear	4.455	0.877***	1.051	Y= a + b x
	Logistic	0.228	0.780***	0.213	Y= ln (bo)+(in(bi)*t)
	Quadratic	3.837	0.902***	0.961	Y= a + b x - cx2
Weed competition	Linear	9.465	0.680***	0.957	Y= a + b x
	Logistic	0.107	0.688***	0.116	Y= ln (bo)+(in(bi)*t)
	Quadratic	10.576	0.932***	0.452	Y= a + b x - cx2

These results are in general agreements with those recorded by Abusteit and Shehata (1993) as theyillustrated that full season of weed competition caused 39.7 and 40.4% reduction in potato tuber yield during 1991 and 1992, per feddan and to avoid significant yield losses, the crop need to be kept weed free for 6-8 weeks after emergence., Ciuberkis, *et al.* (2007) indicated that the critical weed-free period, when weed competition was detrimental to yield, started from planting until 25 days after flowering. The weed competition decreased dry matter accumulation, leaf area index, crop growth rate, light absorption, light extinction coefficient and radiation use efficiency of potato., Monteiro, *et al*. (2011) found that total potato yield ranged from about 22 t/ ha in weed-free plots to about 3 t/ ha with no weed control and equal yield loss of 86% and

Karimmojeni, *et al*. (2013) found that tuber yields of potato were reduced by prolonged delays in weed removal. The practical implication of this study is that weeds must be controlled during the first 3 weeks of the crop's growing season. Such an approach would keep yield loss levels below 5%.

Table 8: Estimation of expected potato tuber yield (ton/feddan) by quadratic model in 2011/12 and 2012/13 winter seasons.

Period	2011/12				2012/13			
	Weed free		Weed competition		Weed free		Weed competition	
	Yield	%	Yield	%	Yield	%	Yield	%
	$\tilde{y}=4.16+0.34x-0.018x^2$		$\tilde{y}=4.16+0.34x-0.018x^2$		$\tilde{y}=4.16+0.34x-0.018x^2$		$\tilde{y}=4.16+0.34x-0.018x^2$	
0	4.2	38	7	100	3.8	17	10.6	100
1	4.5	42	6.7	96	5	22	9.6	90
2	4.9	45	6.4	92	6.3	27	8.7	80
3	5.3	49	6.2	89	7.6	33	7.9	75
4	5.8	54	6	86	9	39	7.3	69
5	6.3	58	5.8	83	10.4	46	6.8	64
6	6.8	63	5.7	82	12	53	6.4	61
7	7.4	69	5.6	80	13.6	60	6.2	59
8	8	74	5.5	79	15.3	67	6.1	58
9	8.7	80	5.5	79	17	75	6.1	58
10	9.4	86	5.5	79	18.9	83	6.3	59
11	10.1	93	5.5	79	20.8	91	6.6	62
12	10.8	100	5.6	80	22.8	100	7	66

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