Impact of Level of Nitrogen Fertilization and Critical Period for Weed Control in Peanut (*Arachis hypogaea* L.)

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Abstract: To avoid competing with economical plants, weed control must be implemented with a clean and appropriate strategy. Since the efficiency of leguminous crops in biological fixation of the atmospheric N_2 is severely affected when grown under stressful conditions (the soil tested in this study was salt-affected; EC_e = 8.99 dS m^{-1}), an appropriate level of N fertilization should also be applied. Two field trials were performed in the 2018 and 2019 seasons to investigate the influences of soil-applied nitrogen (N) levels [48 (N_1), 96 (N_2), and 144 kg N ha^{-1} (N_3)] and critical timing of weed removal (CTWR) on weed control efficiency, improving weed control, yield traits, and quality attributes in peanut (*Arachis hypogaea* L.). Each trial was conducted with three replicates and planned according to a split-plot in a completely randomized design. The results revealed that N levels had significant ($p \leq 0.01$) variations for the dry weight of all weeds tested (narrow-leaved, broad-leaved, and total annual weeds), pods and seed weight and yields, N use efficiency, and oil and protein yields (t ha^{-1}) in peanut in both seasons. N_3 outperformed both N_1 and N_2 with respect to the above-mentioned traits, however, it decreased N use efficiency and seed oil content compared to N_1 and N_2, respectively. Dry weight of weeds and seed harvest index were significantly ($p \leq 0.01$) increased, while seed oil and protein contents, N use efficiency, and yields of pods, seeds, and protein were decreased, with increased weed interference (with peanut plants) period in both seasons. In both seasons, the interaction effect of N × W (weed removal time) was significant ($p \leq 0.01$) on the dry weight of weeds and peanut traits, including seed oil content, N use efficiency, and yields of pods, seeds, and protein, and their highest values were obtained with $N_3 \times W_6$ (weed-free for the whole season). The CTWR had growing degree days (GDDs) of 221.4 and 189. These two GDDs each corresponded to 2 weeks after emergence (WAE) in both growing seasons. The critical weed-free period (CWFP) had GDDs of 1400 and 1380. These two GDDs corresponded to 9.5 and 10 WAE, respectively. The combination of CTWR and CWFP resulted in a critical period of weed control (CPWC) of 2–9.5 and 2–10 WAE in both growing seasons, respectively, for the peanut crop with an acceptable yield loss of 5%. A high positive ($p \leq 0.01$) correlation was noted between oil yield and seed yield (r = 0.999 ** and 0.999 **). However, a high negative ($p \leq 0.01$) correlation (r = −0.723 ** and −0.711 **) was found between dry total annual weeds and seed weight in the first and second seasons, respectively. The stepwise regression analysis revealed high significant participation of two traits (i.e., seed yield and oil content) and three traits (i.e., seed yield, oil content, and weight of seeds) in the variations in oil yield in the first and second seasons, respectively. These results recommend the use of N fertilization at a rate of 144 kg N ha^{-1} in conjunction with keeping the soil free of weeds throughout the season to maximize peanut productivity under saline (8.99 dS m^{-1}) conditions.

Keywords: peanuts; nitrogen; weed removal times; seed yield; oil yield; correlation and stepwise regression

1. Introduction

Peanuts (*A. hypogaea* L.) are the main source of livelihood for many small farmers in the global tropics and subtropics. It is used directly as a food and meal rich in protein and oil, as well as animal feed, especially in Africa and Asia [1,2]. Peanut seed oil contains adequate levels of monounsaturated fatty acids, especially oleic acid. The monounsaturated fatty acids help reduce bad cholesterol and raise the beneficial cholesterol in the human blood. The peanut seeds are an excellent source of *α*-tocopherol (vitamin E), containing around 0.8% by weight [3]. Moreover, peanut seeds provide approximately 85% niacin, which contributes to brain health and blood flow to the brain. Egypt suffers from a severe shortage of edible oils, as the local production of crop seed oils is about 0.34 million t compared to about 2.7 million t required for consumption. This indicates that there is a large gap (87.4%) between domestic consumption and production, which has resulted in the import of edible oils from abroad to meet market demands [4]. To fill this gap, it is necessary to expand peanut cultivation, but many farmlands, especially in dry environments, suffer from either high salinity, lack of irrigation water, or both as a negative factor that limits crop productivity, which also limits the atmospheric N_2 fixation by stressed peanut plants [5]. Another negative factor that limits crop productivity, continuous crop cultivation without proper supplies of fertilizers decreases soil fertility [6], especially N, which is a crucial factor for crop performance in Africa [7,8]. Thus, the supply of mineral N fertilizer is mainly required for the growth and productivity of the peanut crop.

Nitrogen (N) is a major component of many plant functional compounds, such as nucleotides, proteins, chlorophyll, enzymes, alkaloids, vitamins, and hormones [9]. N increases the metabolites that are synthesized due to the increase in the rate of photosynthesis, leading to increased assimilates translocated into crops' edible parts. Recently, many researchers demonstrated that the increased supply of mineral N fertilizer resulted in an increased pod and seed weight per plant, 100-pod and 100-seed weights, as well as pod, seed, oil, and protein yields in peanut [5,10–13]. Therefore, the soil should be supplemented with an appropriate level of N based on crop requirements for better performance of crop plants. Nevertheless, when the plant is grown under open field conditions, it faces many unfavorable conditions during its growth period, including, as in this study, the presence of harmful weeds that compete with the crop plants for food, in addition to the saline conditions of the soil used.

Since peanuts have a small canopy, broad-leaved weeds with strong growth and a large canopy can cover peanut quickly [14], Therefore, weed growth is a limiting factor for crop productivity, including peanut crops. Among different crops, weeds compete with peanut for nutrients, moisture, and light [15]. An appropriate weed control strategy should be used for each crop to optimize the use of herbicides as much as possible to avoid contamination of the agricultural environment. Therefore, an appropriate clean weed control strategy must be implemented to optimize weed control [16–18].

To avoid a reduction in peanut productivity due to weed competition, it has been suggested that weeds should be controlled throughout the season. However, the critical period for weed control (CPWC) in crops is defined as the interval of time between two individually measured weed and crop competition portions: the first is the critical timing of weed removal (CTWR), and the second is the critical weed-free period (CWFP) [19]. Thus, the CPWC is the interval of time during which weed control is important to avert a loss in crop yields. Pod production of peanut is maximized when weeds are removed within 4 weeks after planting (WAP) [20]. It has been determined that the CPWC is intended for peanut 7 to 65 days after planting (DAP) [21] and is intended for total weeds interference in peanut 4 to 9 WAP [22]. The weed dry weight increases with increasing the time of weed interference period, but decreases with increasing the time of weed-free period [23].

Previous studies on the potential enhancements of peanut crop yield, quality, and other growth traits with different N levels and timing of weed control have not been investigated. Therefore, the present study hypothesized that using an adequate mineral N fertilizer and appropriate (best) weed removal times would optimize yield and yield

quality traits of peanut crop and minimize yield loss while effectively reducing weeds by reducing weed competition.

2. Materials and Methods

2.1. Experimental Description

For the current investigation, two field trials were performed for the 2018 and 2019 seasons at the experimental station of the Agriculture College in Fayoum Governorate (29°17′ N, 30°53′ E), Egypt. Sandy loam soil (Table 1) was chosen to study the selection of an appropriate level of mineral nitrogen (N) fertilizer and appropriate weed removal times for annual broad-leaved and narrow-leaved weeds and their influences on yield components and quality traits of peanut plants.

Table 1. Some properties of the tested soil (0–30 cm depth) before sowing.

Property	Unit	Values
Particle size analysis		
Sand		77.4
Silt	%	11.2
Clay		11.4
Soil texture	—	Sandy loam
Soil physical and chemical analysis		
Dry bulk density	$g\ cm^{-3}$	1.67 ± 0.02
Hydraulic conductivity	$cm^3\ h^{-1}$	1.96 ± 0.03
Field capacity		22.4 ± 0.16
Wilting point	%	12.3 ± 0.04
pH *		7.98 ± 0.06
ECe **	$dS\ m^{-1}$	8.99 ± 0.11
CaCO$_3$		7.98 ± 0.07
Organic matter	%	0.92 ± 0.02
Available nutrients		
N		218.4 ± 4.7
P		23.6 ± 0.23
K		119.6 ± 0.92
Zn	$mg\ kg^{-1}$ soil	10.6 ± 0.11
Mn		13.0 ± 0.68
Fe		15.8 ± 0.04
B		3.36 ± 0.05

* Suspension of soil: H_2O (1: 1, *w/v*) and ** Soil paste extract (1: 2.5 soil: H_2O, *w/v*); data are means $\pm$ SE.

The experimental region is classified as semi-arid on the aridity scale [24]. Prior to sowing, the physicochemical characteristics of the tested soil samples taken at a depth of 0–30 cm were evaluated [25] for both seasons and the data are presented in Table 1. Based on the analyses of experimental soil samples, the USDA Soil Taxonomy [26] classifies the tested soil as a sandy loam.

The experimental site was divided into 108 units each with 10.5 m^2 (3.5 m in length × 3.0 m width). Each unit consisted of five rows of 3.5 m in length and 60 cm apart. On the 1st of April in both seasons, the seeds of peanut, cultivar Giza 6, which was secured from the Field Crops Research Institute, the Agricultural Research Center, were planted in hills 10 cm apart, at a rate of one seed per hill (175 seeds per experimental unit; 10.5 m^2). Immediately before planting, the seeds were inoculated with a specific bacterial inoculum (see the details in Section 2.2.). The peanut crop was harvested manually on 15 September in both seasons.

The experiments were laid out in a split-plot design (in a completely randomized design) with three replications for each of 36 treatments (3 N levels × 12 weed treatments), and each replicate was represented by an experimental unit (10.5m^2). Three main plots

were identified for three levels of mineral N fertilizer (Ammonia Nitrate Factory (LDAN) Suez, Egypt), i.e., 48 (N_1), 96 (N_2), and 144 kg N ha^{-1} (N_3). Each main plot was represented by 36 units for 12 weed treatments. Each N level was added in three equal doses; at 15, 30, and 45 days after sowing (DAS). Each main plot (N-level) was divided into 12 subplots identified for 12 weed treatments. Each subplot was represented by three experimental units (three replicates) for each of the 12 weed treatments, which were as follows:

　　W_1 = weed-free until 2 weeks after emergence (WAE),
　　W_2 = weed-free until 4 WAE,
　　W_3 = weed-free until 6 WAE,
　　W_4 = weed-free until 8 WAE,
　　W_5 = weed-free until 10 WAE,
　　W_6 = weed-free for whole season,
　　W_7 = weedy until 2 WAE,
　　W_8 = weedy until 4 WAE,
　　W_9 = weedy until 6 WAE,
　　W_{10} = weedy until 8 WAE,
　　W_{11} = weedy until 10 WAE, and
　　W_{12} = weedy for whole season.

In treatments in which the plots were kept free of weeds, continuous manual weed removing was effectively maintained to preserve the plants in these plots without any weeds being involved.

To determine the beginning of the critical period of weed control (CPWC), as the first step, the weed interference interval (periods of the presence of weed with peanut plant) was increased using the critical timing of weed removal (CTWR) by allowing the annual weeds to compete with the peanut crop for 2, 4, 6, 8, or 10 weeks after emergence (WAE) (referred to weedy treatments), then plots were preserved weed-free up to harvest. To determine the end of the CPWC, as the second step, the critical weed-free period (CWFP) was used to extend the length of the annual weed-free period, by preserving annual weed-free for 2, 4, 6, 8, or 10 WAE (referred to weed-free treatments) before annual weeds were allowed to compete up to the end of the season. No herbicides were used, but weeds were removed manually with the help of small axes and pickaxes along with the hands. The family, scientific, and common names of weeds registered in the peanut field during the 2018 and 2019 seasons are presented in Table 2.

Table 2. Family, scientific, and common names of weeds registered in the peanut field during the 2018 and 2019 seasons.

No	Type of Weeds	Family	Scientific Name	Common Name
1	Annual	Poaceae	*Echinochloa colonum*	Jungle rice
2	narrow-leaved weed	Poaceae	*Digitaria sanguinalis*	Large crabgrass
1	Annual	Asteraceae	*Xanthium brasilicum*	Common cocklebur
2	broad-leaved weed	Portulacaceae	*Portulaca oleraceae*	common purslane
3		Malvaceae	*Hibiscus trionum*	Venice mallow

Calcium superphosphate (15.5% P_2O_5) was used for phosphorus fertilizer that was added at 144 kg P_2O_5 ha^{-1} during seedbed preparation. Potassium sulfate (48% K_2O) was used for potassium fertilizer that was added at 60 kg k_2O ha^{-1} in two equal doses (on 21 and 35 DAS). Faba bean (*Vicia faba* L.) and sugar beet (*Beta vulgaris* L.) were preceding winter crops, cultivated in the 2017–18 and 2018–19 seasons, respectively. Recommended agricultural practices for growing peanuts, including fertilization and surface irrigation times, were followed. In both seasons, peanut plants were irrigated 9 times throughout the season, each of approximately 650 m^3 ha^{-1}. The thermal units through the trial period at Fayoum, Egypt, during the 2018 and 2019 seasons are depicted in Table 3.

Table 3. Growing degree days (thermal units) through the trial period at Fayoum, Egypt, in 2018 and 2019 seasons.

Thermal Units			
Month	**2018 Season**	**Month**	**2019 Season**
1–15 April 2018	221.40	1–15 April 2019	189.0
15–30 April 2018	464.50	15–30 April 2019	408.5
1–15 May 2018	748.15	1–15 May 2019	667.25
1–31 June 2018	1104.19	1–31 June 2019	1059.65
1–15 June 2018	1431.54	1–15 June 2019	1385.15
15–30 June 2018	1785.75	15–30 June 2019	1758.05
1–15 July 2018	2069.44	1–15 July 2019	2043.05
15–31 July 2018	2515.39	15–31 July 2019	2495.45
1–15 August 2018	2817.19	1–15 August 2019	2801.85
15–31 August 2018	3238.89	15–31 August 2019	3230.02
1–15 September 2018	3460.49	1–15 September 2019	3452.7

2.2. Inocula Used and Preparation

Bardyrhizobium spp. (strain USDA 3456) and *Serratia marcescens* (EG 10) were secured from the Biofertilizers Production Unit, Department of Agricultural Microbiology, Soils, Water and Environment Research Institute (SWERI), Agricultural Research Center (ARC), Egypt.

According to Vincent [27] and Atlas [28], Bardyrhizobium spp. and Serratia marcescens were cultured in a yeast extract mannitol broth medium and a King's medium B, respectively. For 3 days, cultures were incubated at 28 °C on a rotary shaker until the early log phase to ensure population density of 109 cfu/mL culture. Powdered vermiculite supplemented with 10% Irish peat (plus 10% wheat bran for fungi inoculant) was packed into polyethylene bags (200 g carrier per bag), then sealed and sterilized with gamma irradiation (5.0 × 106 rads). Each bacterial culture (120 mL of log-phase growing culture) was injected into a sterilized carrier to satisfy 60% of the maximal water holding capacity, then mixed thoroughly and left for a week for curing. One day before sowing, peanut seeds were inoculated with the bacteria (Bardyrhizobium spp. + Serratia marcescens) inocula to guarantee the efficiency of seed inoculation.

2.3. Data recorded

At harvest, to measure the dry weight of weeds (narrow-leaved, broad-leaved, and total annual weeds) in g m^{-2}, weeds were manually removed totally from one m^2 selected randomly in each experimental unit of each subplot. Then, they were identified and categorized into annual broad-leaved and narrow-leaved weeds. The weeds were air-dried for 7 days to reduce the moisture content to increase oven-drying efficiency. Then, the weeds were oven-dried at 75 °C for 48 h until they reached a constant weight. The dry weight (g m^{-2}) was recorded for each weed group.

At harvest, a sample of 10 peanut plants was collected randomly from each experimental unit of each subplot to record pods number and weight (g) per plant, seeds number and weight (g) per plant, and weight of 100 pods and 100 seeds (g).

In each experimental unit of each subplot, plants on the middle two rows were collected at harvest and dried to account for pods, seeds, and straw yield ha^{-1}. The dried pods were hand-shelled, the seeds weighed, and the differences between pods and seed weights of all treatments were used to compute the shelling percentage (%). The shelling (%) was determined based on the weight of the peanut seeds divided by the weight of the pods [29] as follows:

$$\text{Shelling (\%)} = (\text{weight of seeds}/\text{weight of pods}) \times 100 \tag{1}$$

Table 3 displays the growing degree days that were recorded by the Fayoum meteorological station. GDDs were cumulative from the date of sowing with respect to the 10 °C

base temperature [30]. The GDDs values of the peanut crop were computed by using the following equation:

$$GDDs = [\sum (T_{max} + T_{min})/2] - T_{base} \qquad (2)$$

Five plants were randomly selected and harvested with their pods from a sampling row for each experimental unit of each subplot to determine total dry biomass yield at physiological maturity. Then, the aboveground parts were oven-dried with their pods at 75 °C until they reached a constant weight to determine the total dry biomass yield (t ha^{-1}). The seed harvest index (%) was computed as a ratio of the economic (seed) yield to the total dry biomass yield of the plant multiplied by 100 as follows:

$$\text{Seed harvest index (\%)} = [\text{Seed yield (kg)}/\text{Total biomass yield (kg)}] \times 100 \qquad (3)$$

Nitrogen use efficiency (NUE) was computed as kg seeds kg^{-1} N [31] as follows:

$$\text{NUE} = \text{Seed yield (kg)}/\text{Total amount of N fertilizer added (kg)} \qquad (4)$$

Using Grinder Machine (CM-2200, Philippine), samples, each 50 g of seeds obtained from each experimental unit of each subplot were ground until a fine powder. For chemical analysis, the finely powdered samples were stored in brown glass bottles. The seed oil and N contents were assessed practicing the methods depicted in [32]. The protein content in seeds was computed by multiplying the total N content by 6.25 [32]. The total yields of seed oil and protein were calculated per ha by multiplying the seed oil and N contents by seed yield per ha.

2.4. Statistical Analysis

All data collected were statistically analyzed following the analysis of variance (ANOVA) technique for the study design (spilt-plot) as depicted in [33] using MSTAT-C (Michigan, USA). The comparisons of between variables' means were performed using Duncan's multiple range test at a 0.05 probability level ($p \leq 0.05$). For each season, the average yield for each treatment was calculated to be relative to the yield obtained from the seasonal weed-free treatment (RPYL). The starting of CPWC was determined by using the CTWR, and the end of the CPWC was specified by using the CWFP [16] for yield loss levels of 5% and 10%, which was chosen arbitrarily. To compute the CPWC and RPYL for both seasons, data on weedy and weed-free were regressed against the extending interval of the weed interference or extending length of the weed-free period [34].

3. Results

3.1. Impacts of Mineral Nitrogen (N) Fertilization Levels on Weeds and Peanut Traits

The results in Table 4 display that N levels have significant ($p \leq 0.01$) variations for dry weight of all weed groups (i.e., narrow-leaved, broad-leaved, and total annual weeds). The highest N level (N3 = 144 kg N ha^{-1}) outperformed the other two levels (N1 = 48 kg N ha^{-1} and N2 = 96 kg N ha^{-1}). It increased the dry weight of the three weed groups by 30.94% and 17.66%, 43.1% and 19.50%, and 40.24% and 19.06% in the 2018 season, compared to N1 and N2, respectively, and by 33.01% and 21.92%, 51.22% and 14.33%, and 46.24% and 16.12% in the 2019 season compared to N1 and N2, respectively.

Table 4. Effect of nitrogen fertilization levels (N) and time (early and late) weed removal (W) on dry weight of narrow-leaved, broad-leaved, and total annual weeds that accompaniment to peanut (*Arachis hypogaea* L.) in 2018 and 2019 seasons.

Treatment	Dry Narrow-Leaved Weeds		Dry Broad-Leaved Weeds		Dry Total Annual Weeds	
	(g m^{-2})					
	2018	**2019**	**2018**	**2019**	**2018**	**2019**
	Nitrogen (N)					
N_1	146.7c	163.2c	430.4c	433.2c	577.1c	596.4c
N_2	163.2b	178.0b	516.6b	573.0b	679.8b	751.0b
N_3	192.1a	217.1a	617.3a	655.1a	809.3a	872.1a
p-value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
	Weed (W)					
W_1	334.8b	375.7b	1121.5b	1228.1b	1456.3b	1603.9b
W_2	274.7c	300.4c	894.2c	892.3d	1168.9c	1192.7d
W_3	225.6d	261.3d	716.7d	772.5e	942.2d	1033.8e
W_4	135.9f	155.1f	368.5e	395.9f	504.4e	551.0f
W_5	54.4h	48.85h	127.6g	129.8h	182.0g	178.7h
W_6	14.4i	5.32i	34.35h	36.52i	48.70h	41.84i
W_7	14.2i	11.41i	38.10h	39.57i	52.28h	50.97i
W_8	29.7i	30.18hi	66.94gh	66.63hi	96.59h	96.81i
W_9	99.2g	117.6g	113.6g	117.9h	212.8g	235.5h
W_{10}	178.1e	206.1e	229.7f	245.9g	407.8f	452.1g
W_{11}	266.0c	296.5c	952.4c	1003.9c	1218.4c	1300.4c
W_{12}	380.9a	424.6a	1593.6a	1715.9a	1974.5a	2140.5a
p-value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
	N × W interaction					
p-value N×W	0.119 ns	0.301 ns	<0.001 **	<0.001 **	<0.001 **	<0.001 **
CV%	12.6	18.9	13.6	14.1	11.1	11.5

** refer to the significant variation at ($p \leq 0.05$) and ($p \leq 0.01$), respectively, and "ns" point to non-significant variation. Means sharing the same letter in each column are not significantly different at $p \leq 0.05$ by Duncan's multiple range test. N_1 = 48 kg N ha^{-1}, N_2 = 96 kg N ha^{-1}, N_3 = 144 kg N ha^{-1}, W_1 = weed-free until 2 WAE, W_2 = weed-free until 4 WAE, W_3 = weed-free until 6 WAE, W_4 = weed-free until 8 WAE, W_5 = weed-free until 10 WAE, W_6 = weed-free for the whole season, W_7 = weedy until 2 WAE, W_8 = weedy until 4 WAE, W_9 = weedy until 6 WAE, W_{10} = weedy until 8 WAE, W_{11} = weedy until 10 WAE., W_{12} = weedy for the whole season, WAE = weeks after emergence.

The results in Tables 5–8 and Tables S1–S3 also display that N levels have significant ($p \leq 0.01$) variations for pod and seed numbers plant^{-1}, pod and seed weight plant^{-1}, 100-pod and 100-seed weights, seed oil and protein contents, total yields of pods and seeds, N use efficiency (NUE; kg seeds kg^{-1} N), total straw, and oil and protein yields of peanut in the 2018 and 2019 seasons. Significant variation of shelling percentage and seed harvest index was not detected in both seasons. The N3 outperformed the N1 and N2. It increased pods number and weight plant^{-1}, and seeds number and weight plant^{-1} by 33.14% and 15.79%, 34.82% and 19.03%, 32.41% and 15.80%, and 39.09% and 21.78% in the first season, and by 30.29% and 14.68%, 34.91% and 16.73%, 29.59% and 13.14%, and 41.45% and 20.48% in the second season compared to N1 and N2, respectively. N3 also increased the weight of 100 pods, total pods yield, and seed protein content by 21.31%, 47.06%, and 10.19%, and by 23.81%, 48.08%, and 10.26% in both seasons, respectively, compared to N1. It also increased the weight of 100 seeds by 41.71% and by 47.46% in the 2018 and 2019 seasons, respectively, compared to N2. Additionally, N3 increased total yields of seeds, straw, oil, and protein by 55.71% and 21.11%, 61.30% and 24.95%, 52.17% and 20.69%, and 69.70% and 27.27% in the 2018 season, and by 52.74% and 19.89%, 59.86% and 23.49%, 47.95% and 18.68%, and 70.59% and 26.09% in the 2019 season compared to N1 and N2, respectively. On the contrary, N3 decreased NUE and seed oil content by 48.31% and 19.70%, and 0.86% and 0.21% in the first season, and by 49.14% and 20.24%, and 3.01% and 1.18% in the second season compared to N1 and N2, respectively.

Table 5. Effect of nitrogen fertilization levels (N) and time (early and late) weed removal (W) on number and weight of pods plant^{-1} and number and weight of seeds plant^{-1} of peanut (*Arachis hypogaea* L.) in the 2018 and 2019 seasons.

Treatment	Number of Pods plant^{-1}		Weight of Pods (g plant^{-1})		Number of Seeds plant^{-1}		Weight of Seeds (g plant^{-1})	
	2018	2019	2018	2019	2018	2019	2018	2019
Nitrogen (N)								
N_1	15.8c	16.7c	21.9c	22.3c	28.5c	31.0c	18.4c	19.1c
N_2	18.1b	18.9b	24.9b	25.8b	32.6b	35.5b	21.0b	22.5b
N_3	21.0a	21.7a	29.6a	30.1a	37.8a	40.2a	25.6a	27.1a
p-value	<0.001**	<0.001**	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
Weed (W)								
W_1	8.56h	8.89h	13.89g	14.01g	15.40i	15.80h	10.69g	11.09g
W_2	11.67g	12.33g	17.68f	17.15f	21.58g	21.60g	14.41f	16.30f
W_3	16.11e	16.78e	23.34d	22.77e	29.00e	30.34e	19.92d	20.67d
W_4	22.44c	23.22c	30.16c	31.09c	40.40c	44.22c	26.06c	27.08c
W_5	28.44ab	29.67b	38.06ab	39.75ab	51.20ab	56.61ab	33.60ab	35.49b
W_6	29.56a	31.56a	39.20a	41.30a	53.20a	59.40a	34.57a	37.61a
W_7	27.56b	28.44b	36.96b	38.26b	49.60b	54.28b	32.30b	33.80b
W_8	22.56c	23.44c	30.36c	31.95c	40.60c	44.97c	25.81c	27.40c
W_9	19.67d	20.44d	24.18d	24.68d	35.40d	37.39d	20.45d	21.13d
W_{10}	14.56f	15.00f	21.04e	21.57e	26.20f	27.42f	17.38e	18.37e
W_{11}	10.44g	11.44g	16.56f	16.71f	18.86h	20.06g	13.81f	14.63f
W_{12}	7.78h	8.11h	14.04g	13.95g	14.00i	14.9h	10.60g	11.05g
p-value	<0.001 **	<0.001**	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
N × W interaction								
p-value N×W	<0.001 **	0.045 *	<0.001 **	<0.001 **	<0.001 **	0.002 *	0.002 **	0.002 **
CV%	7.3	9.8	6.7	8.8	7.2	9.0	8.2	8.9

*, ** refer to the significant variation at ($p \leq 0.05$) and ($p \leq 0.01$), respectively, and "ns" point to non-significant variation. Means sharing the same letter in each column are not significantly different at $p \leq 0.05$ by Duncan's multiple range test. N_1 = 48 kg N ha^{-1}, N_2 = 96 kg N ha^{-1}, N_3 = 144 kg N ha^{-1}, W_1 = weed-free until 2 WAE, W_2 = weed-free until 4 WAE, W_3 = weed-free until 6 WAE, W_4 = weed-free until 8 WAE, W_5 = weed-free until 10 WAE, W_6 = weed-free for the whole season, W_7 = weedy until 2 WAE, W_8 = weedy until 4 WAE, W_9 = weedy until 6 WAE, W_{10} = weedy until 8 WAE, W_{11} = weedy until 10 WAE., W_{12} = weedy for the whole season, WAE = weeks after emergence.

Table 6. Effect of nitrogen fertilization levels (N) and time (early and late) weed removal (W) on weight of 100 pods and 100 seeds, and N use efficiency of peanut (*Arachis hypogaea* L.) in the 2018 and 2019 seasons.

Treatment	Weight of 100 Pods		Weight of 100 Seeds		N Use Efficiency (kg Seeds kg^{-1} N)	
	(g)					
	2018	2019	2018	2019	2018	2019
Nitrogen (N)						
N_1	111.1c	110.2c	38.4c	37.7c	29.5a	30.7a
N_2	123.6b	123.7b	46.3b	47.0b	18.9b	19.6b
N3	134.7a	136.5a	54.4a	55.7a	15.3c	15.6c
p-value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
Weed (W)						
W_1	66.30f	64.52h	15.32g	15.67i	11.19ef	12.07ef
W_2	80.97e	85.18g	26.08e	25.36g	13.49e	14.38e
W_3	120.0d	119.3e	38.60d	39.42e	18.06d	18.82d
W_4	151.0b	151.4c	61.11b	62.14c	26.87b	27.95b
W_5	170.5a	173.0ab	78.28a	78.75b	31.45a	32.09a
W_6	174.3a	177.7a	80.71a	83.23a	32.42a	33.67a
W_7	169.1a	170.5b	78.52a	78.19c	30.69a	31.45a
W_8	149.2b	149.2c	62.97b	64.13c	28.03b	28.49b
W_9	137.3c	137.3d	48.35c	49.52d	21.55c	21.89c
W_{10}	112.0d	112.0f	29.35e	29.01f	16.66d	17.27d
W_{11}	83.8e	79.18g	21.42f	20.52h	13.45e	14.38e
W_{12}	63.36f	62.21h	15.53g	15.68i	10.68f	11.03f
p-value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
N × W interaction						
p-value N × W	0.135 ns	0.114 ns	<0.001 **	<0.001 **	<0.001 **	<0.001 **
CV%	9.6	5.8	7.8	8.1	12.5	11.8

** refer to the significant variation at ($p \leq 0.05$) and ($p \leq 0.01$), respectively, and "ns" point to non-significant variation. Means sharing the same letter in each column are not significantly different at p ≤ 0.05 by Duncan's multiple range test. N_1 = 48 kg N ha^{-1}, N_2 = 96 kg N ha^{-1}, N_3 = 144 kg N ha^{-1}, W_1 = weed-free until 2 WAE, W_2 = weed-free until 4 WAE, W_3 = weed-free until 6 WAE, W_4 = weed-free until 8 WAE, W_5 = weed-free until 10 WAE, W_6 = weed-free for the whole season, W_7 = weedy until 2 WAE, W_8 = weedy until 4 WAE, W_9 = weedy until 6 WAE, W_{10} = weedy until 8 WAE, W_{11} = weedy until 10 WAE., W_{12} = weedy for the whole season, WAE = weeks after emergence.

Table 7. Effect of nitrogen fertilization levels (N) and time (early and late) weed removal (W) on Scheme 2018 and 2019 seasons.

Treatment	Seeds Oil Content		Seeds Protein Content		Pods Yield		Seeds Yield	
	(%)				(t ha^{-1})			
	2018	2019	2018	2019	2018	2019	2018	2019
	Nitrogen (N)							
N$_1$	48.8a	49.9a	23.5c	23.5c	2.04c	2.08c	1.40c	1.46c
N$_2$	48.5b	49.0b	24.6b	24.6b	2.37b	2.37b	1.80b	1.86b
N3	48.4b	48.4c	25.8a	25.9a	3.00a	3.08a	2.18a	2.23a
p-value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
	Weed (W)							
W$_1$	48.66bcde	49.44b	24.18g	24.22g	1.11f	1.18gh	0.95g	1.03ef
W$_2$	48.71bc	48.85c	24.26fg	24.33fg	1.33f	1.36fg	1.16f	1.21e
W$_3$	48.43ef	48.97c	24.63cd	24.68cd	1.77e	1.80e	1.47e	1.53d
W$_4$	48.43cdef	48.98c	24.78cd	24.81bc	2.85c	2.89c	2.23c	2.32b
W$_5$	48.79b	49.27bc	24.94ab	24.99ab	4.34a	4.33a	2.67a	2.71a
W$_6$	49.25a	49.99a	25.00a	25.08a	4.48a	4.55a	2.75a	2.85a
W$_7$	48.71bcd	49.19bc	24.93ab	24.97ab	4.35a	4.35a	2.61a	2.68a
W$_8$	48.51cdef	48.95c	24.78bc	24.82bc	3.30b	3.36b	2.41b	2.45b
W$_9$	48.46cdef	48.93c	24.66cd	24.69cd	2.14d	2.18d	1.82d	1.84c
W$_{10}$	48.42def	48.90c	24.54de	24.57de	1.59e	1.63ef	1.40e	1.45d
W$_{11}$	48.38f	48.87c	24.42ef	24.49ef	1.32f	1.44fg	1.12f	1.20e
W$_{12}$	48.36f	48.86c	24.33fg	24.38fg	1.07f	1.07h	0.93g	0.94f
p-value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
	N × W interaction							
p-value N×W	<0.001 **	<0.001 **	0.732 ns	0.644 ns	0.001 **	0.007 **	<0.001 **	<0.001 **
CV%	0.5	0.8	0.8	0.7	10.4	11.1	10.0	8.8

** refer to the significant variation at ($p \leq 0.05$) and ($p \leq 0.01$), respectively, and "ns" point to non-significant variation. Means sharing the same letter in each column are not significantly different at p $\leq$ 0.05 by Duncan's multiple range test. N$_1$ = 48 kg N ha^{-1}, N$_2$ = 96 kg N ha^{-1}, N$_3$ = 144 kg N ha^{-1}, W$_1$ = weed-free until 2 WAE, W$_2$ = weed-free until 4 WAE, W$_3$ = weed-free until 6 WAE, W$_4$ = weed-free until 8 WAE, W$_5$ = weed-free until 10 WAE, W$_6$ = weed-free for the whole season, W$_7$ = weedy until 2 WAE, W$_8$ = weedy until 4 WAE, W$_9$ = weedy until 6 WAE, W$_{10}$ = weedy until 8 WAE, W$_{11}$ = weedy until 10 WAE., W$_{12}$ = weedy for the whole season, WAE = weeks after emergence.

Table 8. Effect of nitrogen fertilization levels (N) and time (early and late) weed removal (W) on straw, oil and protein yield, shelling percentage and seed harvest index of peanut (*Arachis hypogaea* L.) in 2018 and 2019 seasons.

Treatment	Straw Yield		Oil Yield		Protein Yield		Shelling (%)		Seed Harvest Index	
	(t ha^{-1})									
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
	Nitrogen (N)									
N$_1$	4.16c	4.21c	0.69c	0.73c	0.33c	0.34c	74.80a	76.94a	0.24a	0.25a
N$_2$	5.37b	5.45b	0.87b	0.91b	0.44b	0.46b	81.32a	83.80a	0.25a	0.25a
N$_3$	6.71a	6.73a	1.05a	1.08a	0.56a	0.58a	78.32a	77.84a	0.24a	0.24a
p-value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	0.343 ns	0.266 ns	0.565 ns	0.439 ns
	Weed (W)									
W$_1$	2.44h	2.43h	0.46gh	0.51fg	0.23g	0.25ef	85.43a	87.76a	0.27a	0.29a
W$_2$	3.14g	3.08g	0.58f	0.60f	0.28f	0.30e	86.44a	88.92a	0.26ab	0.28ab
W$_3$	4.72e	4.81e	0.71e	0.75e	0.36e	0.38d	85.05a	87.54a	0.23c	0.24cde
W$_4$	6.62c	6.72c	1.08c	1.14c	0.55c	0.58b	80.32ab	82.66a	0.24bc	0.25bcd
W$_5$	8.53a	8.64a	1.30a	1.33ab	0.67a	0.68a	61.35c	62.56c	0.21d	0.21e
W$_6$	8.79a	8.90a	1.35a	1.42a	0.69a	0.72a	61.18c	62.64c	0.21d	0.21e
W$_7$	8.45a	8.52a	1.27a	1.32b	0.66a	0.67a	59.78c	61.36c	0.20d	0.21e
W$_8$	7.28b	7.37b	1.17b	1.20c	0.60b	0.61b	73.43b	73.53b	0.23cd	0.23de
W$_9$	6.12d	6.18d	0.88d	0.90d	0.45d	0.46c	84.93a	84.71a	0.22cd	0.22de
W$_{10}$	3.74f	3.79f	0.68e	0.71e	0.35e	0.36d	88.13a	88.86a	0.27a	0.27abc
W$_{11}$	2.84g	2.91g	0.54fg	0.59f	0.28f	0.30e	85.71a	85.61a	0.27a	0.28ab
W$_{12}$	2.28h	2.25h	0.45h	0.46g	0.23g	0.23f	86.02a	88.15a	0.27a	0.28a
p-value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
	N × W interaction									
p-value N×W	<0.001 **	<0.001 **	0.002 **	0.004 **	<0.001 **	<0.001 **	0.785 ns	0.992 ns	0.015 *	0.662 ns
CV%	6.8	8.4	10.2	9.0	9.9	8.9	9.9	11.3	9.9	13.2

*, ** refer to the significant variation at ($p \leq 0.05$) and ($p \leq 0.01$), respectively, and "ns" point to non-significant variation. Means sharing the same letter in each column are not significantly different at p $\leq$ 0.05 by Duncan's multiple range test. N$_1$ = 48 kg N ha^{-1}, N$_2$ = 96 kg N ha^{-1}, N$_3$ = 144 kg N ha^{-1}, W$_1$ = weed-free until 2 WAE, W$_2$ = weed-free until 4 WAE, W$_3$ = weed-free until 6 WAE, W$_4$ = weed-free until 8 WAE, W$_5$ = weed-free until 10 WAE, W$_6$ = weed-free for the whole season, W$_7$ = weedy until 2 WAE, W$_8$ = weedy until 4 WAE, W$_9$ = weedy until 6 WAE, W$_{10}$ = weedy until 8 WAE, W$_{11}$ = weedy until 10 WAE., W$_{12}$ = weedy for the whole season, WAE = weeks after emergence.

3.2. Impacts of Time (Early and Late) Weed Removal on Weeds and Peanut Traits

The data listed in Table 4, Table 8, and Tables S1–S3 display that the dry weight of the three weed groups (i.e., narrow-leaved, broad-leaved, and total annual weeds), shelling percentage, and seed harvest index were significantly ($p \leq 0.01$) increased with increasing the period of weeds interference (W_{12} = weedy for the whole season or late weed removal interval) in both seasons at different N levels. The maximum values of the dry narrow-leaved weeds (380.85 and 424.59 g m^{-2}), dry broad-leaved weeds (1593.63 and 1715.87 g m^{-2}), dry total annual weeds (1974.48 and 2140.47 g m^{-2}), shelling (86.02% and 88.15%), and seed harvest index (0.27 and 0.28) were obtained by increasing the interference intervals because of the late time weed removal in both seasons, respectively. At different mineral N levels, pods and seeds numbers plant^{-1}, pods and seeds weights plant^{-1}, 100-pod and 100-seed weights plant^{-1}, seed oil and protein contents, and NUE, as well as peanut pods, seeds, straw, and protein yields decreased with increasing the period of weeds interference.

In the 2018 and 2019 seasons, the continuation of weed control (weed removal) for the whole season (W_6) increased the number of seeds plant^{-1} by 280.0% and 289.2%, weight of pods by 178.2% and 196.1%, number of seeds plant^{-1} by 280.0% and 298.7%, weight of seeds by 226.1% and 240.4%, weight of 100 pods by 175.0% and 185.7%, weight of 100 seeds by 419.7% and 430.8%, NUE by 203.6% and 205.3%, seed oil content by 1.80 and 2.31%, seed protein content by 2.75% and 2.87%, total pods yield by 318.7% and 325.2%, total seed yield by 195.7% and 203.2%, total straw yield by 285.5% and 295.6%, total oil yield by 200.0% and 208.7%, and total protein yield by 200.0 and 213.04%, respectively, compared to weedy for the whole season (W_{12}).

As depicted in Table 4 and Table S1, the dry weight of annual weeds was determined at the end of the different weed competition periods. The dry weight of weeds increased with an increase in the extent of weed interference interval up to 10 WAE (W_{11} = weedy until 10 WAE) in both seasons. On the contrary, weed dry weight was decreased with an increase in the interval of weed-free period. Peanut pods, seed, oil, and protein yields were significantly ($p \leq 0.01$) influenced by weed interference period under all N levels in both seasons. As shown in Tables 5–8 and Tables S1–S3, the increase in the extent of weed interference interval caused a decrease in the peanut yield and its components under all N levels. The number and weight of pods and seeds per plant, and weight of 100 pods and 100 seeds were increased with an increase in the range of weed-free throughout the season (W_6 = weed-free for the whole season), while decreased with an increase in the extent of weedy for whole season (W_{12}). In general, maintaining a weed-free period beyond 10 WAE (W_5 = weed-free until 10 WAE) until weed-free for the whole season did not bring about any enhancement in the yield of pods, seed, oil, and protein, and yield components such as number of seeds, weight of pods, weight of 100 pods, seed protein content, and N use efficiency as depicted in Tables 5–8. In contrast, the yield of pods, seed, oil, and protein was significantly ($p \leq 0.01$) decreased with the increased extent of weed interference period up to 10 WAE.

The data were determined using the relative peanut yield as a percentage of weed-free for the whole season. An acceptable peanut yield loss threshold of 5% was used to evaluate CWFP and CTWR, and subsequently to calculate CPWC. An acceptable peanut yield damage was used to foretell the onset and end of CPWC and usually calculated from 2% to 5% [26]. CPWC initiation was evaluated using CTWR, and the end of CPWC was evaluated using CWFP [16]. Thus, CPWC is the time duration during which weed control is fundamental to avoid losing the peanut yield and is the duration between the extent of weed competition bearing and the weed-free needed. The CWFP, which is considered to be the time interval in which the peanut crop must stay weed-free from the start of the season to avert a yield loss of 5%, was 1400 and 1380 GDDs, which is roughly equivalent to 9.5 and 10 WAE in both seasons, respectively, as depicted in Figure 1. The CTWR, which is defined as the highest value of time the crop can bear with early-season weed competition before the peanut crop suffers an irreversible loss of production, was 221.5 and 189 GDDs, which

is roughly equivalent to 2 and 2 WAE in both seasons, respectively, which were computed in this study according to the data displays in Figure 1. The CPWC was evaluated based on acceptable yield loss levels (AYLs) of 5% and 10%, which are acceptable given the current economics of weed control [21]. With a yield loss of 10%, the CWFP was 1250 and 1200 GDDs, which is roughly equivalent to 9 and 9.5 WAE in both seasons, respectively, as depicted in Figure 1. The CTWR was 350 and 300 GDDs, corresponding to 3.5 and 3.0 WAE approximately in both seasons, respectively, computed in this study according to the data presented in Figure 1.

Integration of the CTWR of 221.4 and 189 GDDs, corresponding to 2 and 2 WAE approximately in the 2018 and 2019 seasons, respectively, with the CWFP of 1400 and 1380 GDDs, corresponding to 9.5 and 10 WAE approximately in both seasons, respectively, resulted in a CPWC of 2 to 9.5 and 2 to 10 WAE in both seasons, respectively, for peanut crop (Figure 1) at 5% acceptable yield loss. Meanwhile, integration of the CTWR of 350 and 300 GDDs, corresponding to 3.5 and 3 WAE approximately in both seasons, respectively, with the CWFP of 1250 and 1200 GDDs, corresponding to 9 and 9.5 WAE approximately in both seasons, respectively, resulted in a CPWC of 3.5 to 9 and 3 to 9.5 WAE in both seasons, respectively, at 10% AYL.

The CPWC recorded from 2 to 9.5 and from 2 to 10 WAE in both seasons, respectively, at 5% an acceptable peanut yield loss, while it recorded from 3.5 to 9 and from 3 to 9.5 WAE in both seasons, respectively, at 10% an acceptable peanut yield loss, demonstrating the significance of whole-season weed control to avert damage to the peanut yield due to weed interference.

CTWR- (RPY) = $0.6105 X^3 - 5.9726 X^2 + 3.287 X + 97.342$

$R^2 = 0.9912$.

CWFR- (RPY) = $-1.3917 X^3 + 14.059 X^2 - 25.58 X + 47.816$

$R^2 = 0.9992$.
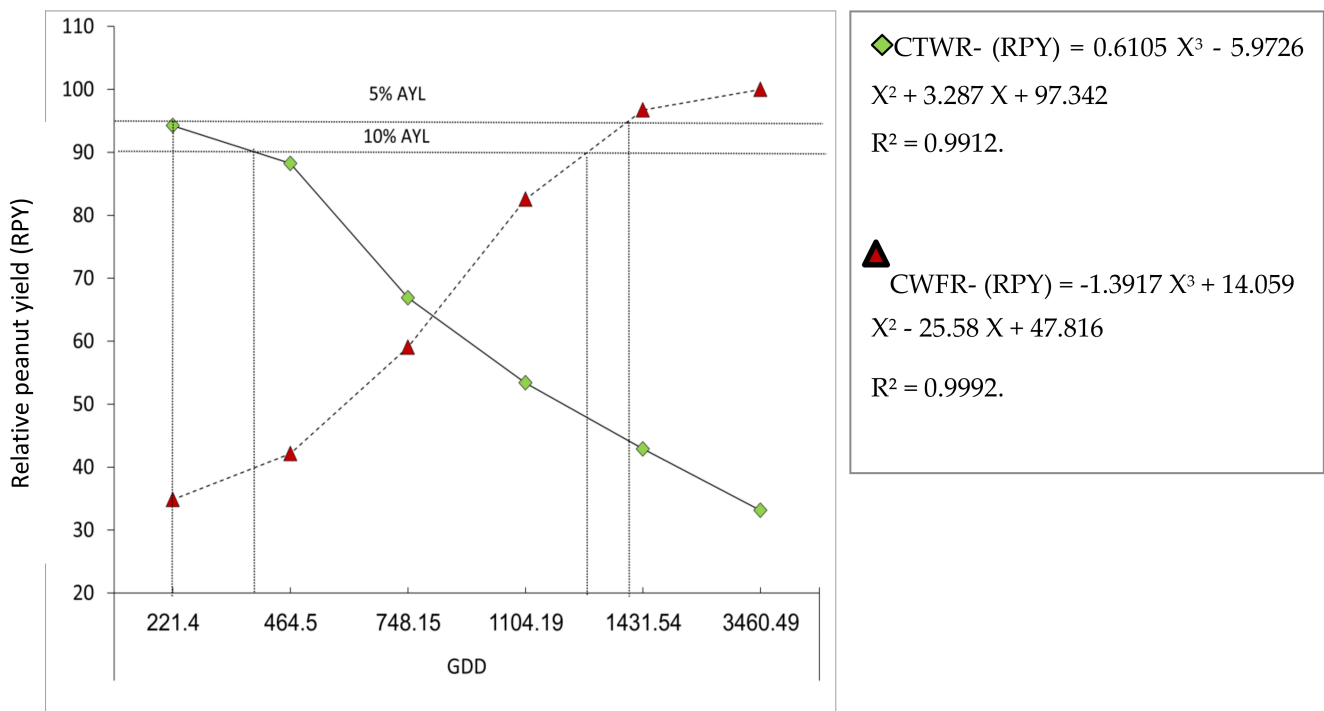
The 2018 season. Growing degree days (GDDs), ◆ CTWR = the critical timing of weed plants removal

Figure 1. *Cont.*
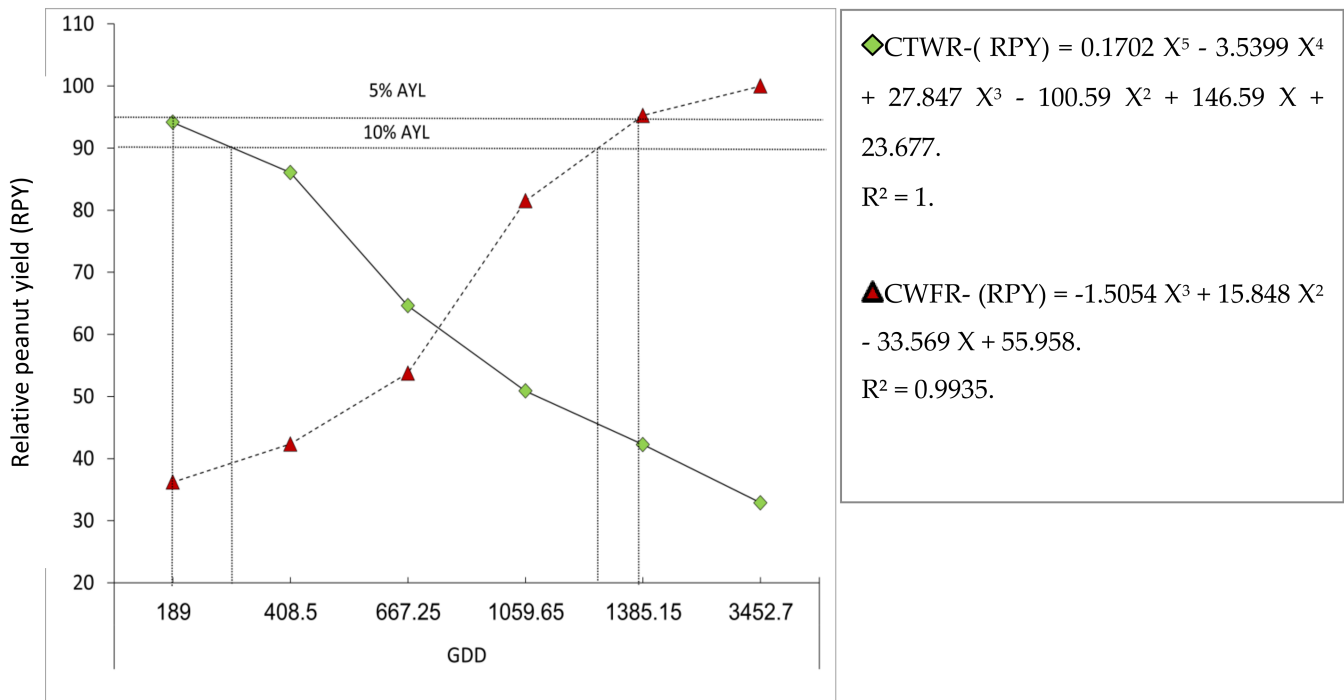
The 2019 season. AYL = accepted yield loss. ▲ CWFR = the critical weed-free period.

Figure 1. Impact of dry total annual weeds interference on relative yield level of peanut in 2018 and 2019 seasons. Increasing duration of dry total annual weeds interference (◆), increasing dry total annual weeds free period (▲), the polynomial equation expresses data for relative yield. The dots and the lines point to relative peanut yield and fitted models, respectively. AYL = accepted yield loss, RPY = relative peanut yield.

3.3. Impacts of the Interaction between Mineral Nitrogen (N) Fertilizer Levels and Time (Early and Late) Weed Removal on Weeds and Peanut Traits

The data in Tables S1–S3 show that the interaction of different levels of N fertilizer and early and late weed removal time (W) significantly ($p \leq 0.01$) affected the dry weight of all weed groups in the 2018 and 2019 seasons. The N x W interaction had a significant ($p \leq 0.05$) effect on the seed harvest index in the 2018 season. No significant variation was detected in dry narrow-leaved weeds, weight of 100 pods, seed protein content, and shelling percentage in both seasons, in addition to seed harvest index in the second season. The maximum values for dry broad-leaved weeds (1931.5 and 2091.5 g m^{-2}), dry total annual weeds (2339.5 and 2550.7 g m^{-2}), and seed harvest index (0.29) were obtained from 144 kg N ha^{-1} (N_3) under the late weed removal time (W_{12} = weed infestation for the whole season). On the other hand, the interaction of N × W significantly ($p \leq 0.01$) affected pods and seeds numbers plant^{-1}, pods and seeds weights plant^{-1}, weight of 100 seeds, seed oil content, NUE, and the yield of peanut pods, seeds, straw, and protein. The highest values for number of pods plant^{-1} (33.67 and 35.33), number of seeds plant^{-1} (60.60 and 65.30), weight of pods (45.98 and 48.39 g plant^{-1}), weight of seeds (41.07 and 43.90 g plant^{-1}), weight of 100 seeds (94.79 and 98.14 g plant^{-1}), pods yield (5.44 and 5.58 t ha^{-1}), seed yield (3.33 and 3.38 t ha^{-1}), straw yield (10.64 and 10.77 t ha^{-1}), oil yield (1.62 and 1.64 t ha^{-1}), and protein yield (0.88 and 0.89 t ha^{-1}) were obtained from N_3 under the early weed removal time (W_6 = weed-free for the whole season). On the contrary, the minimum values for the peanut traits mentioned above were recorded with the late weed removal period (W_{12} = weed infestation for the whole season) at different levels of mineral N. Seed oil content (50.46% and 52.02%) and N use efficiency (44.50 and 46.17 kg seeds kg^{-1} N) were obtained from 48 kg N ha^{-1} (N_1) at the early weed removal time (W_6 = weed-free for the whole season).

3.4. The Stepwise Regression and Correlation Coefficients Analyses

The results in Tables 9 and 10 reveal that the correlation and regression analysis between the oil yield (t ha^{-1}) and each of the independent variables such as pods and seeds weights plant^{-1}, seed oil content, total pods and seed yields, and dry total annual weeds were calculated to focus on the relationship of efficacious peanut traits of interest. A highly positive significant ($p \leq 0.01$) correlation was noted between oil yield and seed yield ($r = 0.999$ ** and 0.999 **), as well as between the dependent variable and pod weight ($r = 0.944$ ** and 0.948 **) and between oil yield and both seed weight ($r = 0.941$ ** and 0.941 **) and pods yield ($r = 0.953$ ** and 0.951 **). Furthermore, highly positive significant ($P \leq 0.01$) correlations ($r = 0.950$ ** and 0.946 **, $r = 0.940$ ** and 0.938 **, and $r = 0.943$ ** and 0.944 **, respectively) were noted between seed yield and pods yield, seed weight, and pods weight in both seasons. On the other hand, highly negative significant ($p \leq 0.01$) correlations ($r = -0.725$ ** and -0.729 **, $r = -0.723$ ** and -0.711 **, $r = -0.710$ ** and -0.701 **, and $r = -0.707$ ** and -0.703 **, respectively) were observed between dry total annual weeds (g m^{-2}) and pods weight, seeds weight (g plant^{-1}), pods yield, and seeds yield (t ha^{-1}) in both seasons, respectively. The stepwise regression analysis in Table 10 reveals the statistically highly significant participation of two traits (i.e., seed yield and oil content) in the first season and participation of three traits (i.e., seed yield, oil content, and seed weight) in the variations in oil yield.

Table 9. A matrix of Pearson's correlation coefficient between oil yield (t ha^{-1}) and other important traits estimated of peanut during two growing seasons.

	Character	1		2		3		4		5		6		7	
		2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
1	Weight of pods (g plant^{-1})	1	1	0.994 **	0.977 **	0.139 ns	0.064 ns	0.954 **	0.953 **	0.943 **	0.944 **	−0.725 **	−0.729 **	0.944 **	0.948 **
2	Weight of seeds (g plant^{-1})			1	1	0.148 ns	0.063 ns	0.950 **	0.945 **	0.940 **	0.938 **	−0.723 **	−0.711 **	0.941 **	0.941 **
3	Seeds oil content					1	1	0.189 *	0.018 ns	0.083 ns	0.141 ns	−0.255 **	−0.225 *	0.107 ns	0.101 ns
4	Pods yield (t ha^{-1})							1	1	0.950 **	0.946 **	−0.710 **	−0.701 **	0.953 **	0.951 **
5	Seeds yield (t ha^{-1})									1	1	−0.707 **	−0.703 **	0.999 **	0.999 **
6	Dry total annual weeds (g m^{-2})											1	1	−0.712 **	−0.716 **
7	Oil yield (t ha^{-1})													1	1

* $p \leq 0.05$, ** $p \leq 0.01$, and ns = not significant.

Table 10. Correlation coefficient (r), coefficient of determination (R^2), and standard error of the estimates (SEE) for predicting oil yield (t ha^{-1}) in two growing seasons.

Season	r	R^2	SEE	Seg.	Fitted Equation
2018	0.999	0.998	0.015	***	Oil yield = −0.982 + 0.484 seeds yield + 0.020 seeds oil content
2019	1.000	1.000	0.008	***	Oil yield = −0.841 + 0.482 seeds yield + 0.017 seeds oil content + 0.001 weight of seed plant^{-1}

*** $p \leq 0.001$.

4. Discussion

In arid and semi-arid regions, crop plants face many environmental foes that adversely affect their performances [35–48]. Given the importance of the peanut crop as a food crop for humans and animals, its medicinal properties, and economic importance for farmers/producers, urgent solutions have to be found to increase peanut productivity under adverse environmental conditions such as poor soil fertility and large weed growth, especially in arid and semi-arid regions. Given the great importance of nitrogen (N) to the plant and the importance of eliminating weeds that greatly reduce crop productivity, these two factors were chosen to study the potential positive influences of supplying peanut

plants with different levels of N fertilizer in conjunction with annual weed control away from the use of herbicides that harm all beneficial organisms, as well as humans and animals. In this study, N was applied at appropriate rates [29] to the tested saline soil (8.99 dS m^{-1}; Table 1) to compensate the peanut plant for its inability to fix the atmospheric N$_2$ under these adverse conditions. Applying the highest level of N (N$_3$ = 144 kg N ha^{-1}) may represent a useful strategy for plants to withstand the adverse conditions of the soil used in the current study (Table 1), given that this soil is salt-affected (EC = 8.99 dS m^{-1}) and tends to be calcareous (CaCO$_3$ = 7.98%). There is research indicating that the use of nitrogen fertilizer increased the crop plant's ability to withstand salinity stress [49,50]. These reports attributed the elevated crop plant's ability to withstand salinity stress and the improved plant's performances (growth and different yields) to the boosted photosynthetic efficiency and the enhanced chlorophyll fluorescence, as well as the enhanced plant's defense system.

Our results displayed that fertilizing the soil with the highest tested level of N (N$_3$) helped peanut plants perform well in terms of productivity, supporting a significant increase in pods, seeds, oil, and protein yields while increasing the fertilizer level N as depicted in Tables 7 and 8. The increment of these yields (i.e., pods, seeds, oil, and protein) due to the use of N$_3$ may be fulfilled as a result of the significance of N in plant nutrition, an improvement of photosynthesis level, an elevation in pods and seeds numbers, pods and seeds weights, weight of 100 pods and 100 seeds, and seed oil content. These positive findings were reflected in the significant increase in seed and oil yields. The results described in [10,11,13] seem to confirm our results.

In recent decades, weed control has been herbicide-dependent in many countries, leading to an increase in the residual toxicity of herbicides, necessitating an improvement in the weed control system that relies less on herbicides [51]. Research in the CPWC considers it of great significance, as it improves time and preserved weed control measures, thus decreasing ecological risks and also enhancing crop productivity and economics of herbicide applications. Therefore, annual weed control in peanut cultivations relies greatly on the application of CPWC. Many researchers also noted the differences in the annual dry weeds of the peanut crop [20–22,52]. As with other field crops, the peanut yield was decreased with an increase in the extent of the weed interference period, while an increase in the extent of the weed-free period increased the yield of peanut. The CPWC recorded from 2 to 9.5 and from 2 to 10 WAE in the 2018 and 2019 seasons, respectively, at 5% an acceptable loss in peanut yield, while it recorded from 3.5 to 9 and from 3 to 9.5 WAE in both seasons, respectively, at 10% an acceptable loss in peanut yield, demonstrating the significance of the whole season weed control to avert damage to the peanut yield due to weed interference. Peanut productivities were decreased with the delay in weed removal and, conversely, yields were increased with increasing the extent of weed-free interval in both seasons. This means that we should not be late in removing weeds from the field. Weeds should be efficiently removed in the period between the beginning of the second week to the tenth week of sowing as a CPWC. This weed control allows us to eliminate weed competition with peanut plants with yield loss not more than 5%. It has been reported that the CPWC was 4.3 to 9 WAP in the peanut crop under the interference weed period [22]. The extended period of weed competition reduced the number and weight of pods and seeds, and the weight of 100 pods and 100 seeds, which was ultimately reflected in a decrease in total seed productivity. Increasing the dry weight of annual weeds while increasing the extent of weed interference interval can also decrease the yields of peanut plants. Using peanut [22,53,54] and *Oryza sativa* crops [23,55,56], the dry weight of weeds has been reported to be correlated with loss in yield. Continued weed control for the whole season (W$_6$) resulted in an increase in the total yields of seeds and oils in the 2018 and 2019 seasons compared to the weed infestation in the whole season (W$_{12}$). These results may be attributed to the minimized competition between weeds and peanut plants, and the enhanced growth traits of the peanut crop (i.e., number of pods and seeds plant^{-1},

weight of 100 pods and 100 seeds, weight of pods and seeds plant^{-1}), which were reflected in the increase in the yield of seeds and oil. Similar findings were also reported in [22,57].

Based on a 5% acceptable yield loss (AYL), our data stipulated that the CWFP was 1400 and 1380 GDDs, and the CTWR was 221.4 and 189 GDDs. The CWFP was 1250 and 1200 GDDs, and the CTWR was 350 and 300 GDDs with 10% AYL in both seasons, respectively, as depicted in Figure 1. Subsequently, weed control must begin after the peanut plants have emergence to prevent yield loss by more than 5% under the experience condition in both seasons. A conceivable reason for beginning earlier to give a permanent longer chance of CPWC might be favorable conditions for germination of weeds and their faster growth. The study describes the importance of the CPWC for sustainable weed control in peanut cultivations. The practicality implicated in our research is that a peanut field must be kept weed-free through 221.4 and 189 GDDs to achieve 95% of a weed-free peanut crop or 350 and 300 GDDs to achieve 90% of a weed-free peanut crop in the 2018 and 2019 seasons, respectively.

5. Conclusions

This work was conducted to shed light on the possibility of affirmative influences of soil-applied N fertilizer and the critical period of weed control (CPWC) for enhancing growth, yields of pods, seeds, oil, and protein, as well as peanut quality and N use efficiency. The increase in N levels from 48 to 144 kg ha^{-1} had significant ($p \leq 0.01$) variations for the dry weight of all weed groups, the different crop yields and quality, and the N use efficiency in both tested seasons. The highest N level (N$_3$ = 144 kg N ha^{-1}) outperformed the other two N levels (48 and 96 kg N ha^{-1}) with respect to the above-mentioned traits. The interaction of 144 kg N ha^{-1} × W (weed removal at early time) was an effective strategy, affecting ($p \leq 0.01$) the dry weight of weeds in both seasons. Integration of critical timing of weed removal (CTWR) with 221.4 and 189 growing degree days (GDDs), which corresponded to 2 and 2 weeks after emergence (WAE) in the 2018 and 2019 seasons, respectively, with critical weed-free period (CWFP) of 1400 and 1380 GDDs, which corresponded to 9.5 and 10 WAE in both seasons, respectively, resulted in a CPWC of 2–9.5 and 2–10 WAE in both seasons, respectively, for peanut crop at an acceptable yield loss of 5%. The highly affirmative significant ($p \leq 0.01$) correlation was noted between the oil yield and the seed yield (r = 0.999 ** and 0.999 **). The stepwise regression analysis revealed the highly significant participation of two traits (i.e., seed yield and oil content) and three traits (i.e., seeds yield, oil content, and weight of seeds) to the variations in the oil yield, in both seasons, respectively. The study results recommend the use of N fertilization at the rate of 144 kg N ha^{-1} in conjunction with keeping the soil free of weeds throughout the season to maximize peanut productivity under saline (8.99 dS m^{-1}) conditions.

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Abbreviations

RCBD	Randomized Complete Block Design
CTWR	Critical Timing of Weed Removal
CWFP	Critical Weed Free Period
CPWC	Critical Period of Weed Control
WAE	Weeks After Emergence
GDDs	Growing Degree Days
AYL	Accepted Yield Loss
RY	Relative Yield
FAO	Food and Agriculture Organization
WAS	Week After Sowing
DAS	Days After Sowing

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