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Cultivation system influenced the critical period for weed control in cotton field

GHALENOVI Narges[1], ARMIN Mohammad[1*] and JAMI MOEINI Matin[1]

Abstract

Background The critical period of weed control (CPWC) refers to the period of time during the crop growth cycle when weeds must be controlled to prevent yield losses. Ultra-narrow row (UNR) is a method of planting of cotton in rows that are 25 cm or less apart. Amongst cultural techniques for weed control, the use of narrow row spacing is considered to be a most promising approach that can effectively suppress weed growth and provide greater yields in cotton. This cultivation system can shorten the length of the critical weed-crop interference duration and results in greater yield. The current research aimed to determination of critical time of weed control in cotton (*Gossypium hirsutum* L.) under conventional and ultra-narrow row spacing conditions. Field experiments were arranged as factorial experiment in a randomized complete block design with three replications. Factors were cultivation system (conventional (50 cm row spacing) and ultra narrow row (25 cm row spacing and weed treatment including 30, 45, 60, and 75 days weeding after emergence during the growing season (weed free), and 30, 45, 60, and 75 without weeding (weed infested) in the growing season along with weedy and weed-free from sowing to harvesting. A four-parameter log-logistic model was fit to the two sets of relating relative crop yield to data obtained from increasing durations of weed interference and lengths of weed-free period.

Results In both years and cultivation systems, the relative yield of cotton decreased with the increasing duration of weed-interference but increased with the increasing duration of weed-free period. Ultra-narrow row cultivation delayed the beginning of the CPWC in cotton. Under ultra-narrow row condition, the CPWC ranged from 21 to 99 days after germination in 2021 and 23 to 91 days in 2022 based on the 5% acceptable yield loss. Under conventional cultivation CPWC ranged from 17 to 102 days after emergence in 2021 and 18 to 95 days after emergence in 2022.

Conclusions Under both conventional and Ultra-narrow row conditions, weed interference reduces seed yield. Under ultra-narrow row condition, weed interference until 21.1–23.5 days after cotton emergence and under conventional condition, weed interference until 16.9–18.5 days after cotton emergence had not significant reduction on cotton yield.

Keywords Cotton, Crop competition, Cultivation system, Integrated weed management, Weed interference

Introduction

Cotton (*Gossypium hirsutum* L.) is one of the oldest crops cultivated in more than 100 countries with the production of about 25 million tons (Khan et al. 2020). The oil, protein, and fibers of this plant are used in human and animal nutrition, respectively, and as the most suitable raw material for textile factories. Currently, 6% of protein and 80% of the world's natural fibers are supplied from cotton (Tokel et al. 2022). In 2022, the cultivated area of cotton in the world was about 32 million hectares, of which 61% of its production was done in Asia, and China, India, the United States, Pakistan, and Brazil are the 5 major producing countries of this product (Shams

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et al. 2022). After sugarcane (*Saccharum officinarum*) and sugar beet (*Beta vulgaris*), cotton is cultivated as the third industrial plant and the first oil crop in Iran.

Due to the very low initial growth rate of cotton, weed can easily overpower this crop. On the other hand, the long duration of cotton growth also causes the presence of various weeds, which makes it necessary to control (Tariq et al. 2020). Weed control is recognized as a necessary step in most crop production systems, because the weed presence, in addition to cotton quantity, has a significant impact on the quality, cost of harvesting, and the diversity and abundance of pests in the field. For this reason, farmers spend large sums of money annually to reduce the harmful effects of weed in crops (Ghavi and Armin 2021). However, in a certain period of plant growth, weed have the most negative impact on the growth and crop yield, which is called the critical period of weed control. In general, it can be said that the critical period is a period of crop growth, in which the field must be kept weed-free to achieve proper yield. Accurately determining or knowing the critical period of weed removal allows producers to design the most appropriate management method of weed control (Knezevic et al. 2002). The critical period for many crops, including cotton, has been determined by others researchers (Bukun 2004; Charles et al. 2019; Knezevic et al. 2002; Raefizadeh et al. 2019; Tursun et al. 2016), for example, based on a 5% acceptable yield loss, the critical period for weed control in cotton has been reported to be 11 days after emergence. Weed that germinated 46 days after cotton emergence did not have significant effects on yield loss in another study, it has been reported that with the increase in the length of the weed interference period, seed-cotton yield decreased, and complete weed interference causes a 96.5% decrease in seed-cotton yield. Accordingly, an 80-day weed-free period has been recommended to achieve proper yield in cotton (Ayyadurai and Poonguzhalan 2011).

Cotton is widely spaced (50 to 70 cm spacing) in many countries, but in most of the major producing countries, a tendency to grow cotton in ultra-narrow row spacing (18 to 25 cm apart) is expanding (Bagherabadi et al. 2019). Nowadays, cultivation in ultra-narrow row spacing method in order to produce higher cotton yields has attracted the attention of researchers. Factors such as earliness (Campuzano-Duque and Buenaventura-Baron 2020), reducing weed growth (Ghavi and Armin 2021), and increasing yield (Bagherabadi et al. 2019) are among the reasons that have increased farmers' income from this method. In the cultivation system with ultra-narrow spacing, the canopy closes about 18 to 36 days earlier than the conventional row spacing (Brodrick et al. 2013). Reducing the width of the row allows better light reception and reduces the possibility of water evaporation (Brodrick et al. 2013). For closed-type cultivars that have less lateral growth, high densities can be used by planting in closer row distances to achieve higher yields, and this method allows producers to use machinery at harvest time (Mehrabadi 2018). The rapid closing of plant cover in the cultivation system with ultra-narrow row spacing causes the reduction of germination, growth, and establishment of weed through shading (Hussain et al. 2022).

The critical period of weed control is influenced by various factors. Under the ultra-narrow row condition, seed-cotton yield losses of 2.5%, 5%, and 10% are estimated to occur 27.42, 36.05, and 44.68 days after emergence, respectively. Also, under the conventional condition, yield losses of 2.5%, 5%, and 10% are estimated to occur 8.1, 13.47, and 24.37 days after emergence, respectively. Under the conditions of cultivation with conventional row spacing, the seed-cotton and fiber yield loss has been observed to begin at 46.3 and 53.73 days after emergence, respectively, while in cultivation with ultra-narrow row spacing the onset of seed-cotton yield loss and fibers yield loss is postponed to 57.9 and 65.9 days after emergence, respectively (Raefizadeh et al. 2019). The differences in the critical period of weed control in different row spacings were reported by Tursun et al. (2016). These researchers reported that the critical period was 117–526 growth degree days at 50 cm row spacing based on 5% acceptable crop yield loss, while at the distance of 70 cm, 98–661 growth degree days were reported as the critical period of weed control.

Due to the widespread use of the planting system with ultra-narrow row spacing, little information is available regarding the critical period of weed control in cotton in this cultivation system. Therefore, the aim of this study was to determine the critical period of weed control in conventional and ultra-narrow row spacing in cotton.

Materials and methods

Experimental site description

The experiment was conducted in 2021 and 2022 in a private farm in Faiz Abad village, Davarzen section of Sabzevar city located 50 km from Sabzevar at latitude 36°13-N, longitude 57°44-E, and 990 m altitude above sea level. According to the Köppen climate classification, the study area had a semi-arid climate with cold winters and hot summers and an average rainfall of 187.7 mm. The maximum and minimum average temperatures are 38.9∘C and 0.44∘C in July and January, respectively. The meteorological data (monthly weather data, maximum and minimum temperature, and total rainfall) are given in Fig. 1. Climate data were obtained from Sabzevar Meteorological Station (Islamic Republic of Iran Meteorological Organization 2022).

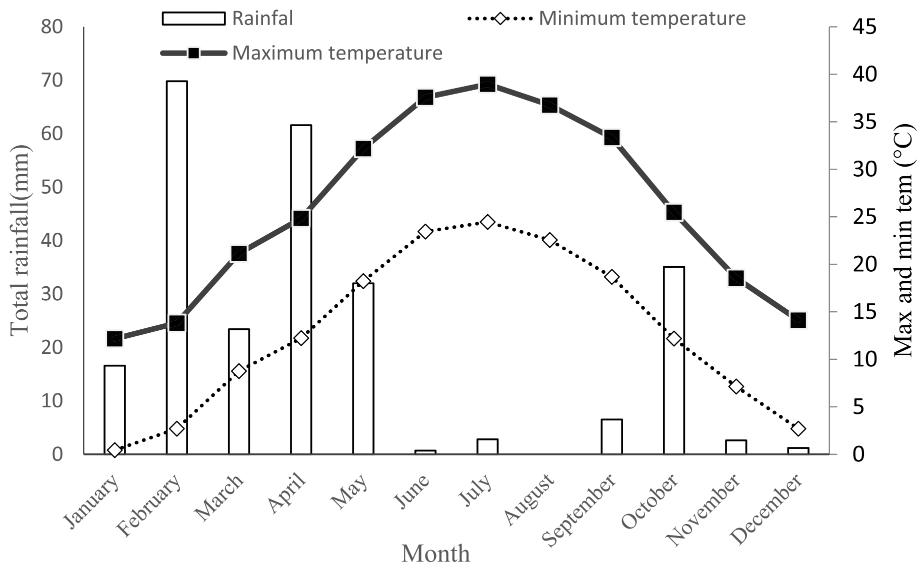

Fig. 1 Maximum and minimum temperatures, and total rainfall in the growing seasons during the 2 experimental years

Experimental design

The studies were laid out in a split-plot arrangement with cultivation method (conventional and ultra-narrow row spacing) as the main plot and timing or duration of weed control treatments. There were two types of weed removal treatments, which were implemented from the start of cotton emergence: (i) plots were left weedy for 30, 45, 60, and 75 days after crop emergence (DAE) to evaluate the onset of the critical period of weed removal and (ii) plots were kept weed-free for 30, 45, 60, and 75 DAE to determine the end of critical period. The season-long weedy (full interference) and weed-free control treatments were also established in the study. In this experiment, the natural flora of weed in the field was used. The average density and composition of dominant weeds at the experimental site were recorded from the season-long, weedy treatment.

Land preparation was done with plowing with moldboard plow immediately after barley harvesting in the first year and after wheat harvesting in the second year, and tillage operation included surface plowing, double-disc plowing, and complete leveling in May. Before planting, soil samples were taken at depths from 0 to 30 cm, and physicochemical properties were determined (Table 1).

Field experiment

According to the soil test, 160 kg·ha^{-1} of nitrogen from urea source was applied in the three stages: planting time (45 kg·ha^{-1}), first weeding (70 kg·ha^{-1}), and early flowering (45 kg·ha^{-1}), along with 70 kg·ha^{-1} of P_2O_5 from triple superphosphate source before planting. Before sowing, the seeds were disinfected with Carboxin-Thiram (Vitavax) at a ratio of 2‰. To combat thrips pests, they were impregnated with Larvin (thiodicarb) at a ratio of 7‰. Each plot consisted of six rows with 5 m length. The distance on the planting row was 20 cm, and the distance between the rows was 50 and 25 cm, in conventional and ultra-narrow row spacing, respectively.

The sowing dates occurred on May 10, 2021, and April 20, 2022, respectively. Planting was done by using the delinted seeds of the Varamin cultivar and a pneumatic sowing machine. The first irrigation was applied immediately after planting via flooding method. The 2nd irrigation was performed ten days later to prevent soil crusting and improve the germination condition of cotton seedlings. Germination took place 17 days after planting. Irrigation was carried out according to the depletion of 40% of the total available water from the root zone during the whole experiment. Irrigation was applied equally to

Table 1 Physicochemical properties of the soil at the experimental site

Manganese /(mg·kg^{-1})	Sodium	Zinc	Copper	Iron	Phosphorus /(mg·kg^{-1})	Potash	Nitrogen /%	Sand /%	Clay	Silt	EC /(dS·m^{-1})	pH$_{(1:5^{a})}$
5.36	20.5	0.65	0.52	2.22	2.85	312	0.043	34	24	42	2.52	7.9

[a] 1:5 soil:deionised water suspension

all treatments, according to the Agricultural and Natural Resources Research Center of Khorasan Province's recommendation (Zabihi et al. 2013). Other required operations were carried out following local customs.

Weed and crop measurement

In order to determine the type and density of weeds, they were sampled in the end of the weed control period of each treatment. Weeds were sampled from two quadrats of 0.5m × 0.5m size. Then every weed was cut close to the ground, separated by species, counted, oven dried at 75°C for 24 h to determine their dry weight. Weed density and weed biomass data was log-transformed (log(10)) due to high variance, whereas no transformation was required for analysis of seed cotton yield. Logarithmic transformation normalized the data.

Harvesting operations were conducted at a single harvest time on November 10, 2021, and November 25, 2022, respectively. Seed cotton yield was measured after manually removing the marginal effects from 3 m^2 of the middle rows of each plot.

Statistical analysis

The four-parameter logistic equation (Eq. 1) was used to determine the response of weed dry matter accumulation to increasing the length of the interference period and obtain the critical period of weed control (Tursun et al. 2016).

$$y = C + \frac{(D - C)}{1 + \exp\left(B\left(\log(x) - \log(ED_{50})\right)\right)}$$

where y is the weed dry matter accumulation, D is the highest amount of weed dry matter during the growing period, C is the lowest amount of weed dry matter during the growing period, B is the relative slope of the curve in the turning point range, x is the day after green and ED_{50} is the days required to achieve 50% of the dry weight of the weed.

Sigma plot software (Ver 14, Systat Software Inpixon) was used to fit the curves and data analysis was done using SAS statistical software (Ver 9.4, SAS Institute). Tables and graphs were drawn using Word and Excel softwares. Average data were compared with Fisher's protected least significant difference (FLSD) method.

Results

Weed density and biomass

Common lambsquarters *(Chenopodium album)*, redroot pigweed *(Amaranthus retroflexus)*, field bindweed *(Convolvulus arvensis)*, prostrate pigweed *(Amaranthus blitoides)*, Bermuda grass *(Cynodon dactylon)*, sweet pea (*Lathyrus odoratus*), and camel thorn *(Alhagi maurorum)* were dominant weeds in the field during the growing season. At the end of the growing season in the complete interference treatment, weed density in ultra-narrow row spacing was 20 and 13 plants·m^{-2} and in conventional row spacing was 30 and 26 plants·m^{-2} in 2021 and 2022. In the ultra-narrow row spacing, common lambsquarters and prostrate pigweed had the highest abundance, while in conventional cultivation common lambsquarters had the highest abundance of weeds. Frequency of redroot pigweed, alhagi, and prostrate pigweed were similar (Table 2). In both planting methods, with the weed interference period increase, the dry weight of weed increased and the highest dry weight of weed was obtained in the entire growing season and conventional cultivation. The coefficients of the four-parameter logistic function showed that the highest dry weight of weed in cultivation with ultra-narrow row spacing was 408 g·m^{-2} while in conventional cultivation the highest dry weight of weed was 503 g·m^{-2} (Fig. 2, Table 3).

Table 2 The mean composition and density of the dominant weed species recorded in the season-long weedy treatment

Weed species	Botanical names	Ultra-narrow row		Conventional	
		Weed density /(plants·m^{-2})	Plants present ratio /%	Weed density /(plants·m^{-2})	Plants present ratio /%
Alhagi	*Alhagi maurorum*	2 (1.63[a])	11.8	4 (1.96)	13.9
Bermuda grass	*Cynodon dactylon*	2 (1.12)	11.8	3 (2.05)	10.03
Common lambsquarters	*Chenopodium album*	3 (1.45)	18.5	5 (3.34)	17.7
Field bindweed	*Convolvulus arvensis*	2 (1.60)	11.8	3 (2.26)	10.03
Prostrate pigweed	*Amaranthus blitoides*	3 (2.29)	18.5	4 (3.75)	13.9
Redroot pigweed	*Amaranthus retroflexus*	2 (1.50)	11.8	4(2.29)	13.8
Sweet pea	*Lathyrus odoratus*	1 (0.97)	5.17	3 (2.29)	10.03

[a] Standard deviation

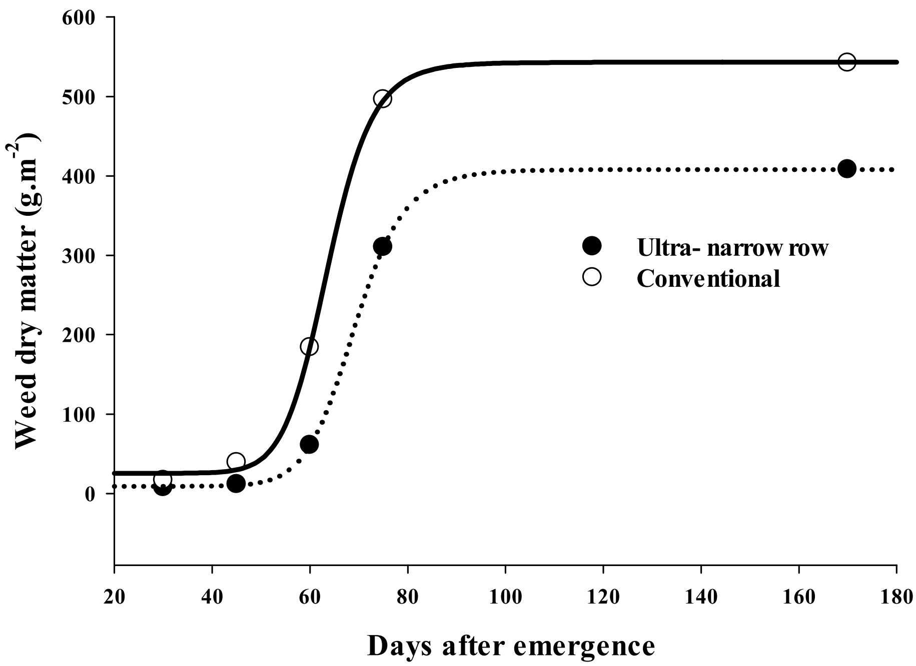

Fig. 2 Effect of cultivation system and different periods of weed competition on weed dry matter accumulation

Table 3 The effect of cultivation system on the time to reach 50% dry weight of weeds and the highest and lowest amounts of dry matter accumulation during the growth season

Cultivation system	B	C	D	ED_{50} (DAE††)	R^2
Ultra-narrow row	31.2 (0.54[a])	408 (1.77)	9.11 (1.28)	69.1 (0.14)	0.99
Conventional	31.9 (4.16)	543 (13.1)	25.6(9.61)	63.6 (0.73)	0.99

B The slope of the line at the inflection point, C The lower limit, D The upper limit, ED_{50} Days after emergence to to gain 50% weight between the upper and lower limits (also known as inflection point)

[a] Estandard errors

†† is abbreviation of DAE

Days after emergence

Seed-cotton yield

Increasing the duration of weed interference in both planting methods decreased seed cotton yield during both seasons significantly; however, the yield losses were higher in the conventional cultivation than in the ultra-narrow row spacing cultivation. Delaying weed control from 30 to 75 DAE resulted in a seed cotton yield loss of 12 kg·ha^{-1} for delay in each day during that period (30–75 DAE) in the ultra-narrow row spacing and 20 kg·ha^{-1} per day in the conventional cultivation (Table 4). In the ultra-narrow row spacing cultivation, there was a yield loss of 7.5%, 12%, 12.5%, and 29% where weeds were allowed to grow until 30, 45, 60, and 75 DAE compared with the weed-free plots, while, in conventional cultivation where weeds were allowed to grow until 30, 45, 60, and 75 DAE compared with the weed-free plots, yield loss was 15.9%, 24.3%, 42.6%, and 47%, respectively. Seed-cotton yield in the ultra-narrow row spacing cultivation where weeds were allowed to grow throughout the crop's duration was 44% more than conventional conditions (Table 4). Although, in all studied treatments, both under the interference conditions and the weed-free conditions, the seed cotton yield in ultra-narrow row spacing cultivation was higher than conventional conditions.

Critical period of control

The coefficients of the four-parameter logistic equation for 2021 and 2022 under two conditions of conventional and ultra-narrow row spacing are shown in Fig. 3 and Table 5. Based on this, the critical period of weed control based on seed yield, including 5% acceptable yield loss threshold in ultra-narrow row spacing in 2021 and 2022 was determined between 21 to 99 days and 23 to 91 days after germination, respectively, and with a 10% yield loss, it was between 27 to 83 days after emergence in 2021 and 28 to 75 days after germination in 2022. While in conventional spacing cultivation, the critical period of weed control is between 17 to 102 days after emergence in 2021 and 18 to 95 days after emergence in 2022. For 10% acceptable yield loss threshold, it was determined between 27 to 80 days after emergence in 2021 and 28 to 60 days after germination in 2022 (Fig. 3, Table 6). With the increase in the period of weed interference, seed yield has a decreasing trend based on the logistic function. The weed-free periods have led to an increase in the seed-cotton yield.

Table 4 Effect of different periods of weed competition on seed cotton yield yield

	Ultra-narrow row		Conventional	
	Seed cotton yield /(kg·ha^{-1})	**Ralative yield compared with weed-free treatment /%**	**Seed cotton yield /(kg·ha^{-1})**	**Ralative yield compared with weed-free treatment /%**
WD[a]30	3313	92.5	2547	84.1
WD45	3157	88.1	2294	75.7
WD60	3133	87.5	1739	57.4
WD75	2539	70.9	1606	53.0
WDhar	2267	63.3	1570	51.8
WF30	2855	79.7	1794	59.2
WF40	3122	87.2	2513	82.9
WF60	3202	89.4	2581	85.2
WF75	3234	90.3	2719	89.7
WFhar	3582	100.0	3030	100.0
LSD 0.05	439		475	

[a] *WD* Weedy until days after crop emergence (DAE) or crop harvest, *WF* Weed free until days after crop emergence or crop harvest

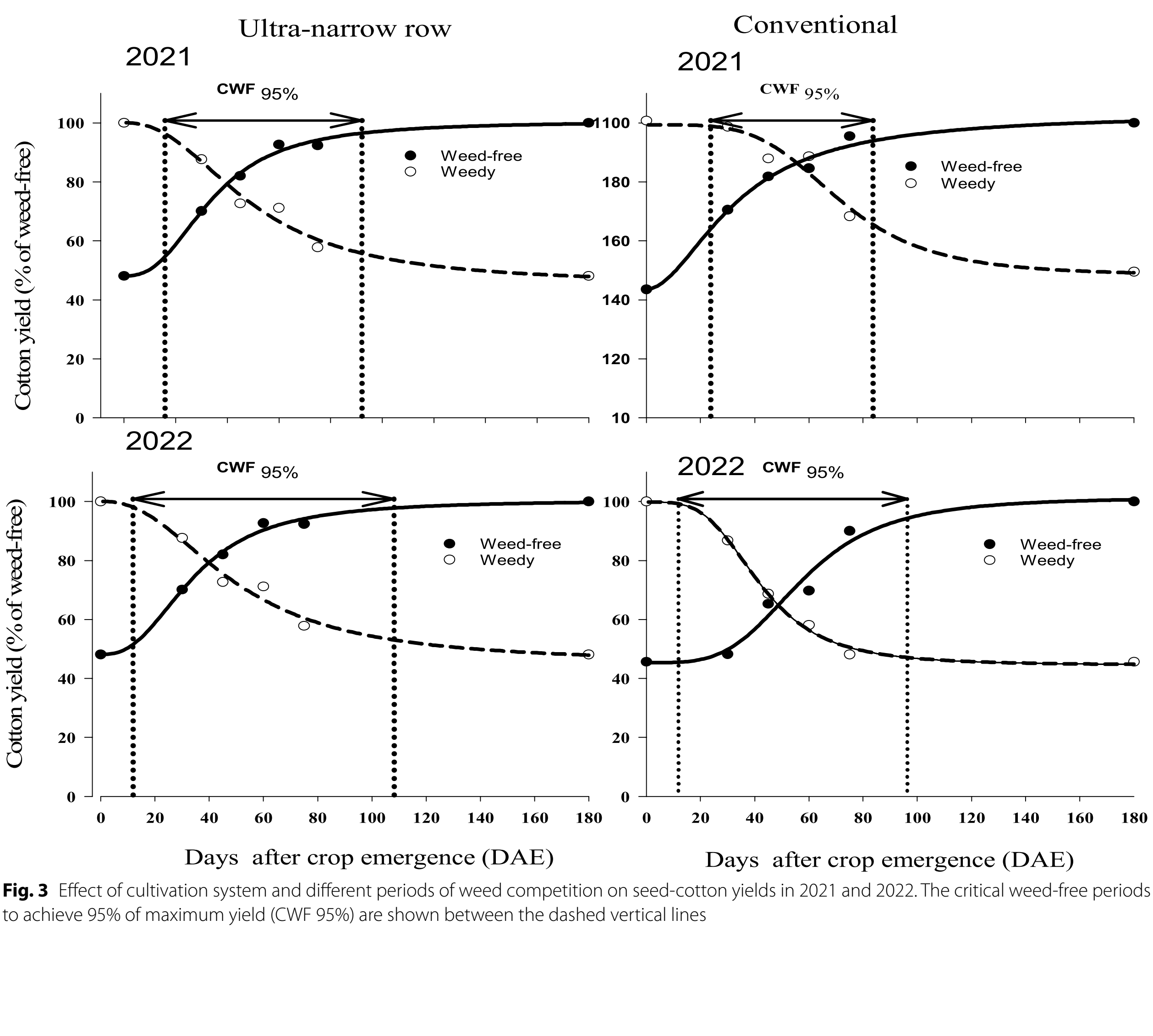

Fig. 3 Effect of cultivation system and different periods of weed competition on seed-cotton yields in 2021 and 2022. The critical weed-free periods to achieve 95% of maximum yield (CWF 95%) are shown between the dashed vertical lines

Discussion

Considerable variation was observed in different weed species in cotton field. Sardar et al. (2015) also reported a combination of broad-leaved and narrow-leaved weed in cotton fields, which is consistent with the results of this research. Ultra-narrow row spacing cultivation reduced the competition of weeds with cotton. It seems that the reason of weed density decreases in the ultra-narrow row spacing cultivation system is the earlier canopy closure, which prevents the germination of weed or it leads to the destruction of weed that are less competitive with cotton, but in the conventional system, the field surface remains empty during most of the cotton growth period, which allows more weed to germinate and grow. Reduction of weed density with increasing density in cotton has also been reported by other researchers (Ghavi and Armin 2021; Hussain et al. 2022; Raefizadeh et al. 2019; Tursun et al. 2016), which is consistent with the results of this research. It was reported that 50 cm row spacing had 42% less weed density (32 plants·m^{-2}) compared with 100 cm row spacing (55 plants·m^{-2}). At the row distance of 50 cm, the weed density decreased with the increase of the interference period, and in the interferences 21, 42, 63, 84, and 154 days after emergence, the weed density was 82, 38, 33, 27, and 13 plants·m^{-2}, respectively. This density was 104, 73, 62, 53, and 39 plants·m^{-2} at a row distance of 100 cm, respectively. Early rainfall received in November during cotton growth resulted in higher weed densities in narrow and wide row spacing (Iqbal et al. 2022).

Ultra-narrow row cultivation caused a linear decrease in the dry weight of weeds. The lower density of weed and the ability of cotton to compete more in obtaining light have reduced the growth and accumulation of dry matter of weed under these conditions. The difference in the highest value of the 4-parameter logistic function was also reported by Tursun et al. (2016). These researchers reported the highest weed dry weight based on the predicted value of the regression function for 50 cm row spacing between 1 170 and 1 280 g·m^{-2}, for 75 cm row spacing between 1 220 and 1 390 g·m^{-2}, and for 90 cm row spacing between 1 620 and 1 710 g·m^{-2}, which indicated that the dry matter of weed was more in the cotton spacing rows, which is consistent with the results of this research. In comparison, Wilson reported

Table 5 Parameter estimates by year and cultivation system for the four-parameter logistic model (Equation 1) characterizing the influence of the duration of weed interference on the relative seed cotton yield

Cultivation system			B	C	D	ED_{50} (DAE††)	R^2
Ultra-narrow row	2021	Weed-free	-8.66 (3.55[a])	45.4(5.29)	101 (6.29)	57.6(6.67)	0.97
	2021	Weed-interference	8.34(1.18)	44.48(2.14)	99.8(2.17)	41.9(2.04)	0.99
	2022	Weed-free	-5.92(1.22)	48.5 (2.67)	100(3.65)	47.9(4.19)	0.99
	2022	Weed-interference	11.6(4.71)	46.72 (7.72)	98.7 (5.63)	40.1(4.23)	0.97
Conventional	2021	Weed-free	-5.30(1.83)	45.24(6.62)	100.06(4.23)	49.41(7.77)	0.98
	2022	Weed-interference	5.83(1.16)	48.13(2.22)	100.4(2.65)	34.23(2.52)	0.997
	2021	Weed-free	-4.31(1.47)	43.6(3.40)	102.9(5.64)	33.4(4.71)	0.99
	2022	Weed-interference	9.84(5.89)	48.21(7.06)	99.35(4.85)	71.56(8.78)	0.98

B The slope of the line at the inflection point, C The lower limit, D The upper limit, ED_{50} Days after emergenc giving a 50% response between the upper and lower limits (also known as inflection point)

[a] Estandard errors

†† is abbreviation of DAE

Days after emergence

Table 6 The critical weed free period and time of weed removal calculated from logistic equations for four levels of crop yield loss in 2021 and 2022 expressed in days after crop emergence (DAE) in different cultivation system

		The critical weed free period				The critical time of weed removal			
		Time (DAE) for indicated % yield loss							
		2%	5%	10%	20%	2%	5%	10%	20%
Ultra-narrow row	2021	119.1	99.5	83.3	66.3	12.6	21.1	27.2	35.6
	2022	118.2	91.4	75.3	65.4	12.9	23.5	28.5	34.6
Conventional	2021	133	102	79.2	56.4	9.25	16.9	24.5	33.4
	2022	112	95.5	59.4	40.8	10.2	18.5	28.1	34.8

that in the narrow row spacing, there is less inter-row space for weed to grow because the crop takes up more space and the plant canopy closes quickly, which is associated with reduced weed growth. Similar findings have been reported in previous studies in which cotton with narrow row spacing (38 cm) reduces weed biomass more compared with cotton grown in wider spacing (102 cm) (Balkcom et al. 2010; Ghavi and Armin 2021; Hussain et al. 2022; Iqbal et al. 2022).

Increasing the length of the control period and reducing the length of the weed interference period increase the important yield components such as the number of bolls per plant and boll weight, which ultimately lead to an increase in seed-cotton yield. The greater seed-cotton yield loss in the conventional cultivation system can be explained by the fact that in wider rows, cotton canopy closes later in the early growth period, which allows the weed to grow more and cause a decrease in yield with more competition, while in ultra-narrow rows, the cotton plant may use the space effectively and minimize the available space for the growth of weed. In addition, the uniform distribution of plants in ultra-narrow row spacing may lead to efficient use of available resources such as nutrients, water, and light. The findings of other researchers also show that in narrow row spacing, the competitive ability of weed is reduced in the access to resources (Ghavi and Armin 2021), weed germination and growth (Raefizadeh et al. 2019), sunlight (Tursun et al. 2016), and weed flora change (Wilson et al. 2007). Raefizadeh et al. (2019) reported that under the condition of complete weed interference, compared with the weed-free treatment, the yield loss rate in the cultivation with ultra-narrow row spacing was 65%, and under conventional conditions was 67%. Although, in all studied treatments, both under the interference conditions and the weed-free conditions, the seed-cotton yield in the cultivation with ultra-narrow row spacing was higher than its yield under conventional cultivation, respectively. In Australia, it has also been shown that, compared with 100 cm row spacing, growing cotton at 50 cm row spacing suppresses weed more effectively and results in higher lint yield (Manalil et al. 2017). These findings are consistent with other studies conducted in Northeastern Australia (Iqbal et al. 2022). and Turkey (Tursun et al. 2016), where cotton with narrow row spacing had a negative effect on weed growth and development, leading to greater reductions in biomass and improvement of fiber yield.

The difference in the beginning and end of the critical period of weed control depends on different weather and management factors. It has been reported that in the rainy years, more weed contamination of the cotton field causes a change in the beginning of the critical period, under this condition weed control should start earlier. Increasing crop density, which has been done due to the reduction of the row spacing, has been accompanied by the increase in the competitive ability of the crop through the increase in height, the initial growth rate, and as a result, reaching the desired leaf area index earlier. In addition, reaching the optimal leaf area index earlier can reduce both the quality and quantity of light received by weed at the bottom of the canopy, which reduces both germination and establishment and the growth of weed, and in this way, it prevents the yield loss (Delaney 2006). The difference in the critical periods of weed control in different row spacings has been reported by Tursun et al. (2016). These researchers reported that at 50 cm row spacing, based on 5% acceptable seed-cotton yield loss, the critical growth period was 117–526 growth degree days, while at 70 cm row spacing, 98–661 growth degree days were reported as the critical period of weed control. Meanwhile, at the 90 cm row distance, 71–714 growth degree days were obtained for the critical weed control period. Raefizadeh et al. (2019) reported that the critical period of weed control starts later in narrower row spacing compared with wider row spacing. The beginning of yield loss in cultivation with ultra-narrow row spacing was reported 57.9 days after germination and in cultivation with conventional row spacing 46.3 days after germination. These researchers believe that in cultivation with ultra-narrow row spacing weed control should be started 42.7 days after planting, based on 2.5% acceptable seed-cotton yield loss, while in cultivation with conventional spacing it starts almost immediately after emergence (12.8 days after emergence). The onset of the critical period in cultivation with ultra-narrow row spacing based on an acceptable yield loss of 5% and 10% was also reported 36.05 and 44.68 days after emergence, respectively, and in cultivation with conventional row spacing it has been reported to be 13.74 and 24.37 days after emergence. Iqbal et al. (2022) reported 42 days after emergence as the onset of the critical period of weed control for cotton grown in narrow row spacing, while it was obtained to be 154 days after emergence for wider row spacing. Weed competition was greater at 100 cm row spacing and resulted in 24%–73% cotton yield loss compared with 18%–66% yield loss at 50 cm row spacing.

Conclusions

In total, the results of this experiment showed that cultivation with ultra-narrow row spacing has a greater ability to reduce the growth and competition of weed compared with the cultivation system with conventional spacing. Based on this, the cultivation with ultra-narrow row spacing by increasing plant density is a suitable agricultural method to reduce the negative effects of weed. The critical period of weed control based on 5% acceptable seed-cotton yield loss, the duration of the weed control period was longer in ultra-narrow row than in the conventional cultivation. The results confirmed that weed control in conventional cultivation should be done earlier than cultivation with ultra-narrow row spacings.

Abbreviations

DAE Days after crop emergence
UNR Ultra-narrow row

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Authors' contributions

Ghalenovi Z carried out the study. Armin M designed the study, analyzed the data, and wrote the main manuscript text, and Jamimoeini M helped fulfill the experiment. All authors reviewed and approved the final manuscript.

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Ethics approval and consent to participate

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Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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