




## Article

# The Influence of Different Row Spacing and Weed Control Intervals on Weed Infestation and Yield-Related Traits of American (*Gossypium hirsutum* L.) and Desi (*Gossypium arboreum*) Cotton

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**Abstract:** Narrow row spacing has attracted significant attention due to its beneficial impacts on weed management in cotton. This study compared the effects of normal and ultra-narrow row spacing on critical periods of weed control in American (*Gossypium hirsutum* L.) and 'Desi' (*Gossypium arboreum*) cotton. Two different row spacings (i.e., recommended (75 cm) and ultra-narrow (30 cm)) and three weed control intervals (i.e., weed control at 30, 60 and 90 days after sowing (DAS)) were included in the study. Weedy-check and weed-free treatments were included in the experiment as controls for comparison. 'Desi' cotton grown under ultra-narrow spacing recorded the lowest weed density and individual density of *Trianthema portulacastrum* L., *Cyperus rotundus* L., *Cynodon dactylon* L., *Echinochloa colona* (L.) Link and *Digera muricata* (L.) Mart. Moreover, 'Desi' cotton sown under ultra-narrow spacing with weed-free and weed control at 30 DAS resulted in the highest leaf area index (LAI), leaf area duration (LAD), net assimilation late (NAR), root elongation rate (RER) and root growth rate (RGR) at all sampling dates. Likewise, 'desi' cotton sown under recommended row spacing and weed-free conditions produced the highest number of sympodial and monopodial branches, number of flowers and bolls per plant, whereas the highest seed cotton yield of 'Desi' cotton was noted under ultra-narrow spacing and weed-free conditions. It is concluded that sowing both cotton types in ultra-narrow row spacing and controlling weeds at 30 DAS will result in lower weed infestation and higher seed cotton yield.

**Keywords:** cotton; weed management; weed density; growth; yield



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## 1. Introduction

Cotton is an important fiber crop around the globe and provides raw materials for several industries [1]. Cotton (*Gossypium hirsutum* L. (American origin), *Gossypium arboreum* (Asiatic origin) and *Gossypium herbaceum* L. (African and Arabian origin)) is a prominent fiber crop around the world [2,3]. American cotton (*G. hirsutum* L.), after its introduction to the New World, occupied the cropped area previously cultivated with local cotton species [4]. American cotton provides raw materials to world's textile industry and possesses a high global economic impact (USD 600 billion) [4]. The fiber quality of American cotton is the major reason of its widespread popularity. It is a rich source of edible oil and provides animal feed and biofuel.

The average cotton yield in Pakistan is 618 kg ha<sup>-1</sup> [5], which is lower than other cotton producing countries in the world, including Mexico (1644 kg ha<sup>-1</sup>), Israel (2009 kg ha<sup>-1</sup>), Australia (1889 kg ha<sup>-1</sup>), China (1758 kg ha<sup>-1</sup>), Russia (1759 kg ha<sup>-1</sup>) and Brazil

(1658 kg ha<sup>-1</sup>) [5,6]. Several factors are responsible for low cotton yield in Pakistan, including suboptimum plant population, non-judicious use of fertilizers, unlevelled land, high pest infestation and non-availability of effective herbicides for weed management [3].

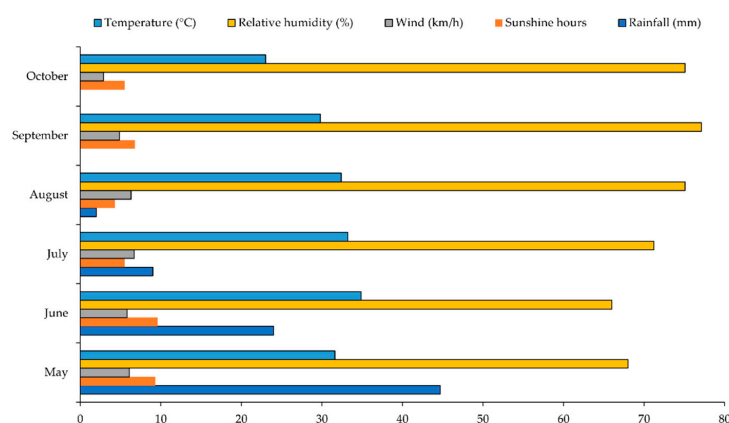
Weeds compete with cotton plants and restrict their growth and development [7]. Furthermore, weeds interfere with other field operation, thus increasing production costs [8]. Depending on the climate, management, plant density and row spacing, cotton may entirely cover the land area, although this can take a considerable amount of time. Poor weed management in the early growth stages of cotton might result in a lower yield. When cotton is planted at a conventional row spacing of 1 m, a weed-free period of 9–11 weeks is necessary to obtain higher yield. The sowing of cotton crop in wider rows results in severe weed infestation as wider rows provide substantial space for weeds' growth [9,10]. Weeds can emerge quickly, have rapid growth, and produce large quantity of seeds if not controlled with herbicides, tillage, or crop competition [11]. The herbicides should be supplemented with other weed management options due to rising concerns on environmental pollution and evolution of herbicide resistance [12,13]. Therefore, reducing the space available to weeds could serve as an effective approach to control weeds' infestation [9]. Row spacing could be included in integrated weed management programs to increase crop competition against weeds [14].

Alternative agronomic strategies are needed to maintain optimum plant population for cotton crop [15]. Usually, farmers in Pakistan grow cotton in 75 cm wider rows, which results in the extended growth period and irregular sympodial branches [16]. Moreover, optimum plant density is extremely important to harvest high cotton yields. Low plant density will result in the waste of resources, whereas optimum plant density will result in the efficient utilization of resources [17]. Ultra-narrow row spacing is a sustainable agronomic technique to reduce yield losses in cotton by increasing plant density [17,18]. It provides optimum aeration which increases seed cotton yield by maintaining inter-node distance, uniform boll formation, increasing boll weight and shortening life cycle [19]. Narrow row cotton with higher plant density produces higher dry mass [20] and leaf area index [20] compared to conventional row cotton system.

The 'Desi' cotton (*G. arboreum*) produces a significantly higher seed cotton yield with narrow row spacing compared to conventional row spacing because of a higher number of fruiting branches, flowers, and bolls m<sup>-2</sup> due to a higher plant population. The 'Desi' cotton is indigenous to Pakistan and has evolved from *G. herbaceum*. Most of the cotton germplasm of 'Desi' cotton has been acquired within a few varieties due to low cross-pollination or mixing of the seeds. Natural selection carried out on a single population led to the development of cultivars with a narrow genetic basis. Hence, the yield of 'Desi' cotton is increased by maintaining high plant population through narrow row spacing [10,21]. The 'Desi' cotton is an indigenous species originated in Pakistan and has a highly spreading nature compared to American cotton. The 'Desi' and American cotton may differ in their weed suppressing ability. Therefore, this study tested weed infestation and yield-related traits of American and 'Desi' cotton grown under recommended and ultra-narrow row spacing.

## 2. Materials and Methods

This study was conducted at the research area of Department of Agronomy, Bahaud-din Zakariya University, Multan, Pakistan during the spring season of 2019. Soil samples (0–20 cm depth) were collected before sowing to evaluate the fertility status of experimental field. The soil was clay-loam with pH of 8.30, soil organic matter content of 0.49%, 2.22 dS m<sup>-1</sup> EC, 0.023% available nitrogen (N), 122 mg kg<sup>-1</sup> available potassium (K) and 8.10 mg kg<sup>-1</sup> of dry soil available phosphorous (P). Meteorological data during the whole experimental period were recorded and presented in Figure 1.



**Figure 1.** Weather data of the experimental site during the study period (May–October, 2019).

### 2.1. Experimental Details

The experiment was laid out in a randomized complete block design with factorial arrangements with three replications and a net plot size of  $2.4 \times 5$  m. The seeds of ‘Desi’ cotton (*G. arboreum*) genotype ‘D-9’ were procured from a local market. Similarly, the seeds of American cotton (*G. hirsutum*) genotype ‘IUB-2013’ were procured from the Islamia University of Bahawalpur, Pakistan. Weeds were allowed to grow during early stages except for weed-free plots and then weeds were removed at 30, 60 and 90 days after sowing (DAS) by hand hoeing. Weeds were not controlled in the weedy-check treatment until crop harvest.

### 2.2. Crop Husbandry

Pre-soaking or ‘rouni’ irrigation (10 cm depth) was applied prior to seedbed preparation. Sowing was done on 15 May 2019 by hand drill. Row spacing was maintained according to the treatments (i.e., recommended = 75 cm and ultra-narrow row spacing = 30 cm). Delinted seeds of both cotton types were used in sowing. Thinning was done to maintain plant to plant distance of 30 cm in both row spacings. Crop nutrient requirement was fulfilled by applying  $120 \text{ kg ha}^{-1}$  N,  $100 \text{ kg ha}^{-1}$  P and  $60 \text{ kg ha}^{-1}$  K. The whole amount of P and K was applied at sowing, whereas N was applied in three equal splits, i.e., at sowing and with 1st and 2nd irrigations (25 and 40 DAS). Major insect-pests observed in the field were whitefly (*Bemisia tabaci*), aphid (*Aphis gossypii*), jassid (*Amrasca biguttula*), thrips (*Thrips tabaci*), dusky cotton bug (*Oxycarenus laetus*) and boll worms. Nitenpyram + chlorfenapyr ( $375 \text{ g/ha}$ ) was applied to control jassid and thrips, and flonicamid + abamectin ( $1000 \text{ g ha}^{-1}$ ) was applied to control aphid, jassid, thrips and dusky cotton bug. Boll worms were controlled by using lambda cyhalothrin ( $775 \text{ mL ha}^{-1}$ ).

### 2.3. Data Recorded

#### 2.3.1. Weeds Density

The density of total and individual weeds was recorded by using  $1 \text{ m}^2$  quadrat from each experimental unit. The quadrat was randomly placed at three different places in each experimental unit. Total and individual number of weeds present in each quadrat were counted and averaged. The weed density was recorded at 45, 60 and 90 DAS.

#### 2.3.2. Allometric and Root Related Traits

Leaf area and leaf area index were measured from five randomly selected plants in each experimental unit. Leaf area was measured by using leaf area meter (DT Area meter, Model MK2, Delta T Devices, Cambridge, UK). The LAI was calculated by using Equation (1) given by Watson [22].

$$\text{Leaf area index} = \frac{\text{leaf area}}{\text{ground area}} \quad (1)$$

Leaf area duration (LAD) was recorded by using Equation (2) proposed by Hunt [23].

$$\text{LAD} = \frac{(\text{LAI}_1 + \text{LAI}_2) \times (t_2 - t_1)}{2} \quad (2)$$

where  $\text{LAI}_2$  is the leaf area index calculated at  $t_2$ ;  $\text{LAI}_1$  is the leaf area index calculated at  $t_1$ ;  $t_1$  = first harvest time;  $t_2$  = second harvest time.

Three plants were randomly selected from each experimental unit to measure crop growth rate (CGR). The plants were harvested, weighed fresh and brought to the laboratory and dried at 70 °C for 72 h. The dried samples were weighed on electronic balance. Sampling was started at 60 DAS and continued until 105 DAS with 15 days intervals. The dry weight of plants was converted to dry weight  $\text{m}^{-2}$ . The CGR was then calculated using Equation (3) suggested by Hunt [23].

$$\text{Crop growth rate} = \frac{W_2 - W_1}{t_2 - t_1} \quad (3)$$

Here,  $W_2$  = dry weight at 2nd harvest,  $W_1$  = dry weight at first harvest,  $t_2$  = time at 2nd harvest, and  $t_1$  = time at 1st harvest.

Net assimilation rate (NAR) was recorded using Equation (4) given by Beadle [24].

$$\text{NAR} = \frac{\text{TDM}}{\text{LAD}} \quad (4)$$

where TDM = dry matter measured in  $\text{gm}^{-2}$  and LAD = Leaf area duration measured in days.

Three plants were uprooted carefully to avoid any damage to roots and root length was measured. Sampling was started at 60 DAS and terminated at 105 DAS with 15 days intervals. Then root elongation rate was measured using Equation (5).

$$\text{Root elongation rate} = (L_2 - L_1)/(t_2 - t_1) \quad (5)$$

Here,  $L_1$  is the first root length measured at  $t_1$  (time of first harvest), and  $L_2$  is root length calculated at  $t_2$  (time of 2nd harvest).

Root growth Rate was measured using Equation (6).

$$\text{Root growth rate} = (W_2 - W_1)/(t_2 - t_1) \quad (6)$$

Here,  $W_1$  is root dry weight at  $t_1$  (time of first harvest), and  $W_2$  root dry weight calculated at  $t_2$  (time of 2nd harvest).

### 2.3.3. Morphological and Yield Related Traits

Ten randomly selected plants from each experimental unit were used to record average number of sympodial and monopodial branches per plant. The flowers and bolls from the same plants were counted and averaged. Seed cotton yield was recorded by taking two pickings from each plot and converted to  $\text{kg ha}^{-1}$ .

### 2.4. Statistical Analysis

Collected data were analyzed using Fisher's Analysis of Variance (ANOVA) technique. The data were normally distributed [25]; therefore, the analyses were executed on original data. Three-way ANOVA was used to test the significance of the data. The means were then separated using the least significant difference test at 95% probability level where ANOVA indicated significant differences [26]. The statistical computations were executed on SPSS statistical software version 21.0. Interactions between cotton types, row spacing and weed control treatments were significant; therefore, these were used for the interpretation of the results instead of individual effects.

### 3. Results

#### 3.1. Total and Individual Weed Density ( $m^{-2}$ )

Weed control treatments (WC) had non-significant effect on the density of total weeds. Cotton types (CT), different row spacing (S) and three-way interaction of CT, S and WC had significant effect on individual and total weed density (Tables 1–3).

**Table 1.** The effect of different row spacing and weed control intervals on individual density of *Trianthema portulacastrum* and *Cyperus rotundus* in ‘Desi’ and American cotton.

Treatment	<i>Trianthema portulacastrum</i>					<i>Cyperus rotundus</i>				
	Desi Cotton		American Cotton		Means WC	Desi Cotton		American Cotton		Means WC
	30 cm	75 cm	30 cm	75 cm	30 cm	75 cm	30 cm	75 cm	30 cm	
45 DAS										
WC	10.67 e	11.67 c–e	16.33 ab	11.67 c–e	12.58	13.67 c	16.00 a–c	19.33 a	14.67 c	15.92
WF	-	-	-	-	-	-	-	-	-	-
WC30	10.33 e	16.33 ab	12.00 b–e	11.67 c–e	12.55	13.33 c	19.33 a	15.00 bc	14.67 c	15.58
WC60	11.00 e	16.00 a–c	11.67 c–e	12.33 a–e	12.75	16.00 a–c	19.00 a	14.67 c	17.00 a–c	16.67
WC90	10.67 e	16.67 a	11.33 de	15.6 a–d	13.58	13.67 c	19.67 a	14.43 c	18.67 ab	16.58
Means S	9.40 B		11.20 A			12.00 B		13.90 A		
Means CT	10.33		10.27			13.07		12.83		
LSD value at 5% for S = 1.45, WC = 2.29, CT = 1.45, S × WC × CT = 4.59						LSD value at 5% for S = 1.22, WC = 1.92, CT = 1.21, S × WC × CT = 3.85				
60 DAS										
WC	15.67 cd	16.00 b–d	17.6 a–d	19.67 ab	17.25	22.67 cd	23.00 b–d	24.67 a–d	26.67 ab	24.25
WF	-	-	-	-	-	-	-	-	-	-
WC30	-	-	-	-	-	-	-	-	-	-
WC60	14.67 d	17.33 a–d	17.6 a–d	20.33 a	17.50	21.67 cd	24.43 a–d	24.67 a–d	27.33 a	24.50
WC90	15.67 cd	18.67 a–c	17.6 a–d	20.67 a	18.17	22.67 cd	25.67 a–c	24.67 a–d	27.67 a	25.17
Means S	9.90		11.27 A			14.20 B		15.47 A		
Means CT	9.80 B		11.37 A			14.00 B		15.57 A		
LSD value at 5% for S = 1.17, WC = 1.85, CT = 1.16, S × WC × CT = 3.69						LSD value at 5% for S = 1.17, WC = 1.85, CT = 0.71, S × WC × CT = 3.69				
90 DAS										
WC	19.67 e	23.67 bc	22.33 cd	25.67 a	22.83	23.67 d	24.00 cd	25.67 b–d	27.67 ab	25.25
WF	-	-	-	-	-	-	-	-	-	-
WC30	-	-	-	-	-	-	-	-	-	-
WC60	-	-	-	-	-	-	-	-	-	-
WC90	19.67 e	26.00 a	21.00 de	24.67 ab	21.83	23.67 d	26.67 a–c	25.67 b–d	28.67 a	26.17
Means S	8.27 B		10.00 A			9.86		10.70		
Means CT	8.90		9.37			9.80 B		10.77 A		
LSD value at 5% for S = 0.61, WC = 0.97, CT = 0.61, S × WC × CT = 1.94						LSD value at 5% for S = 0.91, WC = 1.43, CT = 0.90, S × WC × CT = 2.86				

WC = weedy-check; WF = weed-free; WC30 = weed control at 30 DAS; WC60 = weed control at 60 DAS; WC90 = weed control at 90 DAS; W = weed control intervals; CT = cotton type; S = row spacing. Means followed by lower case letters denote differences among interactive effect, whereas means followed by upper case letters indicate the differences among individual effects of applied treatments.

**Table 2.** The effect of different row spacing and weed control intervals on individual density of *Cynodon dactylon* and *Echinochloa colona* in ‘Desi’ and American cotton.

Treatment	<i>Cynodon dactylon</i>					<i>Echinochloa colona</i>				
	Desi Cotton		American Cotton		Means WC	Desi Cotton		American Cotton		Means WC
	30 cm	75 cm	30 cm	75 cm	30 cm	75 cm	30 cm	75 cm	30 cm	
45 DAS										
WC	4.67 ef	6.00 b–e	5.00 ef	7.0 bc	5.67	0.67 b–d	0.67 b–d	0.33 cd	1.00 a–c	0.67
WF	-	-	-	-	-	-	-	-	-	-
WC30	5.00 ef	5.67 c–e	4.00 f	7.0 bc	5.42	1.33 ab	1.00 a–c	1.00 a–c	1.67 a	1.25
WC60	5.67 c–e	9.00 a	6.0 b–e	6.0 b–e	6.58	0.67 b–d	1.33 ab	1.33 ab	1.33 ab	1.17
WC90	4.00 f	6.67 b–d	5.33 d–f	7.33 b	5.83	0.67 b–d	0.67 b–d	1.67 a	1.00 a–c	1.00
Means S	3.93 B		5.47 A			0.77		0.87		
Means CT	4.67		4.73			0.70		0.93		
LSD value at 5% for S = 0.46, WC = 0.73, CT = 0.46, S × WC × CT = 1.45						LSD 5% for S = 0.30, WC = 0.48, CT = 0.71, S × WC × CT = 0.97				
60 DAS										
WC	9.33 d	11.00 c	11.00 c	13.00 b	11.08	2.33 bc	2.11 d	2.33 bc	1.67 c	2.17
WF	-	-	-	-	-	-	-	-	-	-
WC30	-	-	-	-	-	-	-	-	-	-
WC60	9.67 d	12.00 bc	12.00 bc	14.67 a	12.08	1.67 c	3.67 a	2.33 bc	3.67 a	2.83
WC90	9.00 d	13.00 b	11.00 c	15.00 a	12.00	2.00 bc	4.00 a	2.67 b	4.00 a	3.17
Means S	6.20 B		7.87 A			1.33 B		1.93 A		
Means CT	6.40 B		7.67 A			1.60		1.67		
LSD value at 5% for S = 0.38, WC = 0.60, CT = 0.37, S × WC × CT = 1.19						LSD value at 5% for S = 0.29, WC = 0.46, C = 0.29, S × WC × CT = 0.92				
90 DAS										
WC	14.00 de	15.67 bc	14.6 c–e	18.00 a	15.58	2.67 e	5.00 c	4.00 d	8.00 a	4.92
WF	-	-	-	-	-	-	-	-	-	-
WC30	-	-	-	-	-	-	-	-	-	-
WC60	-	-	-	-	-	-	-	-	-	-
WC90	13.67 e	15.00 b–d	16.00 b	17.33 a	15.50	3.00 e	6.00 b	5.67 bc	6.33 b	5.25
RS means	5.83 B		6.60 A			1.53 B		2.53 A		
CT means	5.83 B		6.60 A			1.67 B		2.40 A		
LSD value at 5% for S = 0.19, WC = 0.62, CT = 0.39, S × WC × CT = 1.24						LSD 5% for S = 0.29, WC = 0.46, CT = 0.29, S × WC × CT = 0.92				

WC = weedy-check; WF = weed-free; WC30= weed control at 30 DAS; WC60 = weed control at 60 DAS; WC90 = weed control at 90 DAS; WC = weed control intervals; CT= cotton types; S = row spacing. Means followed by lower case letters denote differences among interactive effect, whereas means followed by upper case letters indicate the differences among individual effects of applied treatments.

Ultra-narrow row spacing (UNRS) recorded lower weed density, while recommended row spacing resulted in higher weed density at all sampling dates (45, 60 and 90 DAS) (Table 3). The ‘Desi’ cotton recorded lower total weed density compared to American cotton at all sampling dates (Table 3). Further, both cotton types recorded higher total weed density when weed control was done at 60 DAS (Table 3). Three-way interaction of CT, S and WC revealed that ‘Desi’ cotton sown under UNRS with all WC treatments recorded lesser total weed density at all sampling dates (Table 3). Results regarding individual weed density revealed that CT, S and interaction between S × CT and WC significantly affected the density of *Trianthema portulacastrum*, *Cyperus rotundus*, *Cynodon dactylon*, *Echinochloa colona* and *Digera muricata* at all sampling dates (Tables 1–3).



**Table 3.** The effect of different row spacings and weed control treatments on individual density of *Digera muricata* and total weed density in *desi* and American cotton.

Treatment	<i>Digera muricata</i>					Total Weed Density				
	Desi Cotton		American Cotton		Means WC	Desi Cotton		American Cotton		Means WC
	30 cm	75 cm	30 cm	75 cm	30 cm	75 cm	30 cm	75 cm	30 cm	
45 DAS										
WC	2.67 ef	4.00 a–e	3.00 d–f	5.00 ab	3.67	32.33 d	34.00 b–d	44.00 a–c	39.33 a–d	38.17
WF	-	-	-	-	-	-	-	-	-	-
WC30	3.00 d–f	4.43 a–d	2.00 f	5.00 ab	3.58	33.00 d	43.67 ab	34.00 cd	40.00 a–d	38.42
WC60	3.33 c–f	4.00 a–e	4.00 a–e	4.00 a–e	3.75	34.67 cd	45.33 a	37.00 b–d	39.00 a–d	40.00
WC90	2.00 f	4.67 a–c	3.33 c–f	5.33 a	3.83	31.00 d	44.43 a	36.00 b–d	48.00 a	40.83
Means S	2.30 B		3.63 A			28.20 B		34.77 A		
Means CT	2.80		3.13			27.23 B		31.23 A		
LSD 5% for S = 0.49, WC = 1.12, CT = 0.49, S × WC × CT = 1.58						LSD 5% for S = 3.39, WC = 2.64, CT = 3.39, S × WC × CT = 2.24				
60 DAS										
WC	9.00 d–f	9.00 d–f	11.6 a–c	9.67 c–e	9.83	59.0 e–g	61.33 d–g	67.33 b–d	70.67 a–c	64.58
WF	-	-	-	-	-	-	-	-	-	-
WC30	-	-	-	-	-	-	-	-	-	-
WC60	7.33 f	12.00 ab	9.00 d–f	8.33 ef	9.17	55.00 g	69.33 b–d	65.67 c–e	74.43 ab	66.08
WC90	8.00 ef	13.00 a	8.33 ef	10.6 b–d	10.00	57.33 fg	74.43 ab	64.43 c–f	78.00 a	68.50
Means S	5.33 B		6.27 A			36.87 B		42.80 A		
Means CT	5.83		5.77			37.63 B		42.03 A		
LSD 5% for S = 0.71, WC = 1.12, CT = 0.71, S × WC × CT = 2.24						LSD 5% for S = 2.58, WC = 2.58, CT = 0.71, S × WC × CT = 3.24				
90 DAS										
WC	10.67 de	12.33 c	12.67 bc	14.43 a	12.50	70.67 e	84.43 c	80 d	95.67 a	82.67
WF	-	-	-	-	-	-	-	-	-	-
WC30	-	-	-	-	-	-	-	-	-	-
WC60	-	-	-	-	-	-	-	-	-	-
WC90	10.00 e	14.00 ab	12.00 cd	15.33 a	12.83	70 e	91.00 b	79.67 e	92.33 ab	83.25
Means S	4.53 B		5.60 A			30.03 B		36.33 A		
Means CT	4.70 B		5.43 A			31.60 B		34.77 A		
LSD 5% for S = 0.51, WC = 0.80, CT = 0.71, S × WC × CT = 1.61						LSD 5% for S = 1.36, WC = 2.16, CT = 1.37, S × WC × CT = 4.43				

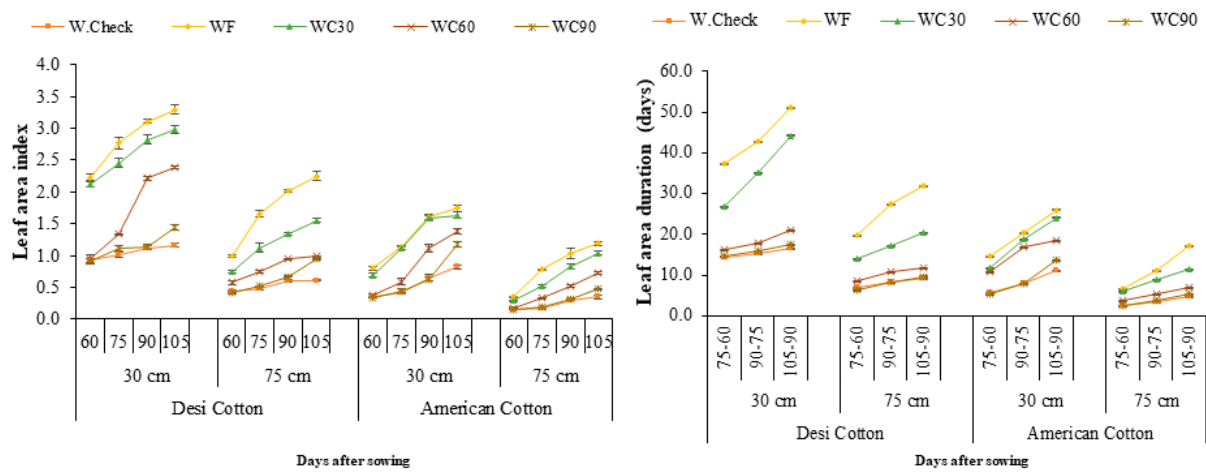
WC = weedy-check; WF = weed-free; WC30= weed control at 30 DAS; WC60 = weed control at 60 DAS; WC90 = weed control at 90 DAS; WC = weed control intervals; CT= cotton types; S = row spacing. Means followed by lower case letters denote differences among interactive effect, whereas means followed by upper case letters indicate the differences among individual effects of applied treatments.

However, WC had non-significant effect on the density of *T. portulacastrum*, *C. rotundus*, *C. dactylon*, *E. colona* and *D. muricata* on all sampling dates, while CT had non-significant effect on the density of these weed species at 45 DAS. Moreover, S had a non-significant effect on the density of *T. portulacastrum* at 60 DAS, *C. rotundus* at 90 DAS and *E. colona* at 45 DAS (Tables 1–3). The ‘Desi’ cotton recorded the lowest density of *T. portulacastrum*, *C. rotundus*, *C. dactylon*, *E. colona* and *D. muricata* on all sampling dates, while American cotton recorded higher density of these weed species (Tables 1–3). The crop sown under UNRS presented lower density of *T. portulacastrum*, *C. rotundus*, *C. dactylon*, *E. colona* and *D. muricata* compared to recommended row spacing. Three-way interaction revealed that American cotton with recommended spacing and weedy-check treatment resulted in the highest density of *T. portulacastrum*, *C. rotundus*, *C. dactylon*, *E. colona* and *D. muricata* on all sampling dates. The ‘Desi’ cotton sown under UNRS and weed-free treatment resulted in

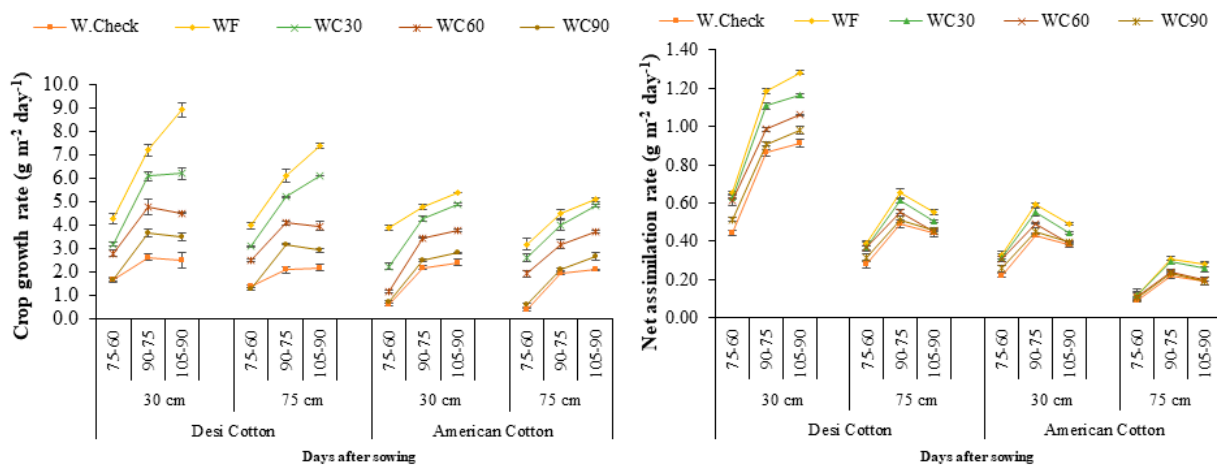
the lowest density of *T. portulacastrum*, *C. rotundus*, *C. dactylon*, *E. colona* and *D. muricata* (Tables 1–3).

### 3.2. Allometric and Root Related Traits

Leaf area index (LAI), leaf area duration (LAD), crop growth rate (CGR) and net assimilation rate (NAR) started to increase from 60 DAS until 105 DAS (Figures 2 and 3). The ‘Desi’ cotton sown under UNRS produces higher LAI, LAD, CGR and NAR on all sampling dates compared to American cotton (Figures 2 and 3). The lowest values for LAI, LAD, CGR and NAR were noted for American cotton sown under recommended spacing. Weed-free treatment recorded the highest values of LAI, LAD, CGR and NAR, whereas weedy-check treatment resulted in the lowest values of these traits (Figures 2 and 3).



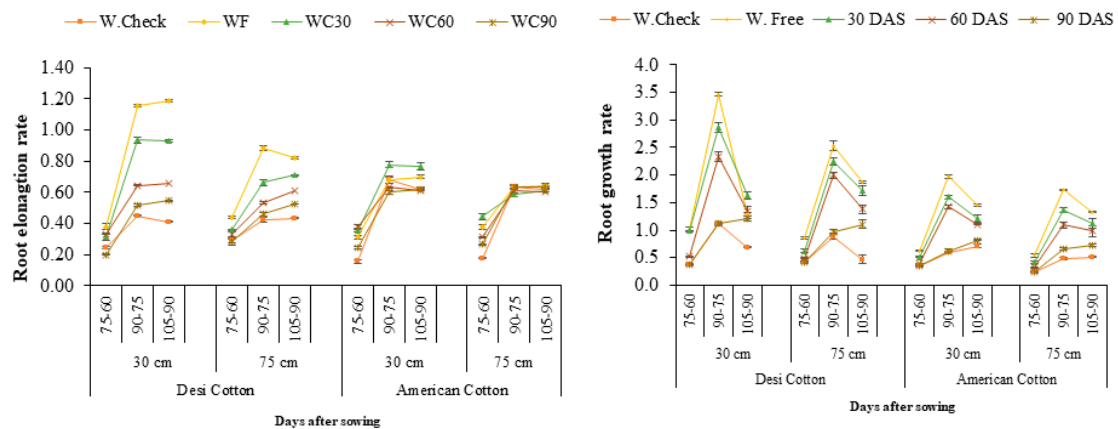
**Figure 2.** The influence of different row spacings and weed control treatments on leaf area index and leaf area duration of ‘Desi’ and American cotton.



**Figure 3.** The influence of different row spacings and weed control treatments on crop growth rate and net assimilation rate of ‘Desi’ and American cotton.

Data on root traits revealed that root elongation rate (RER) and root growth rate (RGR) increased from 75–60 DAS, attained the highest values at 90–75 DAS and then started declining until 105–90 DAS (Figure 4). The ‘Desi’ cotton sown under UNRS resulted in higher RER and RGR, while American cotton sown under recommended row spacing resulted in the lowest values of these traits (Figure 4). Similarly, the highest and the lowest values of these traits were recorded under weed-free and weedy-check treatments, respectively (Figure 4).





**Figure 4.** The influence of different row spacings and weed control treatments on root elongation rate (cm/day) and root growth rate (g/day) of ‘Desi’ and American cotton.

3.3. Yield-Related Traits

The individual effects of CT, S and WC and their three-way interaction had significant effect on number of monopodial and sympodial branches, flowers and bolls per plant, and seed cotton yield (Tables 4 and 5). American cotton produced a higher number of monopodial and sympodial branches compared to ‘Desi’ cotton, whereas ‘Desi’ cotton resulted in a higher number of flowers and bolls per plant and seed cotton yield compared to American cotton (Tables 4 and 5). The ‘Desi’ cotton sown under recommended row spacing produced a higher number of monopodial and sympodial branchers per plant and a higher number of flowers and bolls per plant, whereas it produced a higher seed cotton yield under UNRS (Tables 4 and 5). Crops sown under weed-free treatment produced a higher number of monopodial and sympodial branches per plant, a higher number of flowers and bolls per plant and seed cotton yield, while weedy-check and WC at 90 DAS resulted in the lowest values of these traits (Tables 4 and 5). Interaction among CT × S × WC revealed that ‘Desi’ cotton sown under recommended row spacing and weed-free treatment produced the highest number of monopodial and sympodial, and the highest number of flowers and bolls per plant compared with American cotton sown under weedy-check treatment (Tables 4 and 5). Moreover, ‘Desi’ cotton sown under UNRS and weed-free treatment recorded the highest seed cotton yield, whereas the lowest seed cotton yield was recorded for American cotton sown under recommended row spacing and weedy-check and WC at 90 DAS (Tables 4 and 5).

**Table 4.** The impact of different weeds control intervals on number of monopodial and sympodial branches and flowers plant<sup>-1</sup> of ‘Desi’ and American cotton under recommended and ultra-narrow rows spacing.

Treatments	Number of Monopodial Branches Plant <sup>-1</sup>					Number of Sympodial Branches Plant <sup>-1</sup>					Number of Flowers Plant <sup>-1</sup>				
	Desi Cotton		American Cotton		Means WC	Desi Cotton		American Cotton		Means WC	Desi Cotton		American Cotton		Means WC
	30 cm	75 cm	30 cm	75 cm		30 cm	75 cm	30 cm	75 cm		30 cm	75 cm	30 cm	75 cm	
WC	8.67 g-i	10.67 fg	5.67 l	6.67 kl	7.92 E	28.67 g-i	36.67 ef	16.67 l	20.67 kl	25.67 E	65.33 i	72.0 h	17.0 n	18.33 mn	43.17 E
WF	15.00 c	18.67 a	8.33 h-j	9.33 gh	12.83 A	54.00 c	68.67 a	27.33 h-j	31.33 gh	45.33 A	197.0 b	207.0 a	27.0 k	30.00 j	115.25 A
WC30	13.67 d	17.00 b	7.33 jk	8.33 h-j	11.58 B	48.67 d	62.00 b	23.33 jk	27.33 h-j	40.33 B	185.0 d	192.0 c	25.0 kl	27.33 k	107.42 B
WC60	11.33 e	15.33 c	6.67 kl	7.67 i-k	10.25 C	39.33 e	55.33 c	20.67 kl	24.67 i-k	35.00 C	95.0 f	133.0 e	20.67 m	23.33 l	68.00 C
WC90	9.67 fg	13.00 d	5.67 l	6.67 kl	8.75 D	32.67 fg	46.00 d	16.67 l	20.67 kl	29.67 D	74.0 h	87.0 g	17.67 n	19.00 mn	49.17 D
Means S	9.20 B		11.33 A			30.80 B		39.33 A			72.4 B		80.90 A		
Means CT	13.30 A		7.23 B			47.20 A		22.93 B			130.77 A		22.53 B		
LSD 5% S = 0.37, WC = 0.58, CT = 0.36, S × WC × CT = 1.16					LSD 5% S = 1.47, WC = 2.33, CT = 2.33, S × WC × CT = 4.66					LSD 5% for S = 0.84, WC = 1.32, CT = 0.83, S × WC × CT = 2.64					

WC = weedy check; WF = weed free; WC30 = weed control at 30 DAS; WC60 = weed control at 60 DAS; WC90 = weed control at 90 DAS; WC = weed control intervals; CT = cotton type; S = row spacing. Means followed by lower case letters denote differences among interactive effect, whereas means followed by upper case letters indicate the differences among individual effects of applied treatments.

**Table 5.** The impact of weeds control intervals on number of bolls per plant and seed cotton yield of ‘Desi’ and American cotton under recommended and ultra-narrow rows spacing.

Treatments	Number of Bolls Plant <sup>-1</sup>					Seed Cotton Yield (kg ha <sup>-1</sup> )				
	Desi Cotton		American Cotton		Means WC	Desi Cotton		American Cotton		Means WC
	30 cm	75 cm	30 cm	75 cm		30 cm	75 cm	30 cm	75 cm	
WC	69.00 h	82.00 f	38.00 o	45.67 m	58.67 E	744.70 p	717.20 q	713.90 q	579.40 s	688.8 E
WF	144.43 a	130.00 b	61.33 j	66.33 i	93.00 A	1543.30 a	1477.21 b	1285.00 e	1165.30 f	1367.7 A
WC30	107.00 d	119.33 c	56.00 k	56.00 k	84.58 B	1461.40 c	1357.22 d	1051.10 h	983.30 j	1213.3 B
WC60	83.00 f	94.00 e	44.67 m	50.67 l	68.08 C	1111.11 g	1026.10 i	873.11 l	755.00 o	941.3 C
WC90	79.00 g	83.33 f	41.00 n	46.67 m	62.50 D	958.67 k	850.61 m	791.91 n	687.8 r	822.2 D
Means S	69.33 B		77.40 A			1053.4 A		959.9 B		
Means CT	96.10 A		50.63 B			1124.8 A		888.6 B		
	LSD 5% for S = 0.71, W = 1.12, C = 0.71, S × W × C = 2.24					LSD value at 5% for S = 1.44, W = 2.28, C = 1.44, S × W × C = 4.56				

WC = weedy check; WF = weed free; WC30 = weed control at 30 DAS; WC60 = weed control at 60 DAS; WC90 = weed control at 90 DAS; WC = weed control intervals; CT = cotton type; RS = row spacing. Means followed by lower case letters denote differences among interactive effect, whereas means followed by upper case letters indicate the differences among individual effects of applied treatments.

#### 4. Discussion

Different row spacings and weed control treatments significantly altered weed infestation, allometric and yield-related traits of ‘Desi’ and American cotton. The highest weed infestation was noted under weedy-check treatment, which resulted in the lowest values of yield and related traits. Likewise, ‘Desi’ cotton resulted in the lower weed infestation and higher seed cotton yield compared to American cotton. The UNRS recorded higher seed cotton yield and lower weed infestation compared to recommended row spacing. The differences among cotton types are thought to be the result of their genetic make-up and growth traits as well as environmental conditions. The differences among row spacings are directly linked with higher plant population of cotton and lower space available for weed infestation. Similarly, the differences among weed control treatments are linked with the critical period of weed competition as weeds are easily controlled at their initial growth phase compared to the late developmental phase. Weed-suppressing abilities of crop varieties significantly vary. Herbicide use and weed control expenses might be reduced by including competitive cultivars into cropping systems. Plant height, leaf area development, and branching patterns influence weed competitiveness of cultivars. Cotton plants develop new branches and widen their canopy until maturity. Weeds will not be able to compete with cotton as early in the crop establishment stage if the canopy is closed, resulting in reduced light penetration into the inter-row areas. The differences in the cotton types are owed to their ability to develop canopy. The ‘Desi’ cotton has a spreading nature and develops canopy quickly compared to American cotton. The quick canopy developed by ‘Desi’ cotton reduced light penetration; thus, weeds were unable to grow. On the other hand, American cotton developed canopy slowly, which helped the weeds grow until the development of canopy.

The UNRS resulted in the lower total weed density and density *T. portulacastrum*, *C. rotundus*, *C. dactylon*, *E. colona* and *D. muricata* as compared recommended row spacing. It might be due to higher plant population and less light penetration under UNRS which enables the cotton plants to compete well with weeds for available resources. A non-chemical strategy capable of controlling many invasive and established weeds is to increase plant density. The dense crop stands often increase crop yields, improve weed control, and lower weed management costs. Increasing plant density would cause early canopy closure, which would restrict light penetration into the gaps between the rows and suppress dominant weeds. This strategy could efficiently control the weeds that thrive well in non-competitive environments; however, it performs poorly under increased com-

petition. The reduced weed infestation in UNRS in the current study is the result of early canopy closure and competition with the weed plants. Therefore, increasing plant density through narrow spacing could efficiently control weeds. Our results are consistent with Mashingaidze et al. [27], Chauhan and Johnson [14] and Tursun et al. [9] who reported that decreasing row spacing improves crop competitive ability against weeds. Likewise, 'Desi' cotton presented a lesser number of weeds per unit area compared with American cotton. It might be due to higher plant height and closed canopy of 'Desi' cotton compared to American cotton. Kulkarni et al. [28] reported that 'Desi' cotton is more resistant to several biotic and abiotic stresses compared to American cotton.

Both cotton types produced significantly higher LAI and LAD under UNRS compared to the recommended row spacing. The 'Desi' cotton had significantly higher LAI and LAD than American cotton which might be due to its canopy being larger than that of American cotton (Figure 2). Darawsheh et al. [20], Brodrick et al. [17] and Pettigrew and Meredith [29] also reported similar results. The LAI and LAD of both cotton types was higher in weed-free treatment compared to the weedy-check that might be due to weeds competition for available resources as reported by Blaise et al. [10]. The dry matter of both cotton types was higher in UNRS than recommended row spacing under all weed control treatments which increased CGR and RGR (Figure 3). The 'Desi' cotton had significantly higher CGR, RGR, and NAR than American cotton under both row spacing and all weed control treatments. The results regarding CGR and RGR reported by Darawsheh et al. [20] in relation to row spacing are similar to our results. Similarly, 'Desi' cotton had higher plant height than American cotton in all weed control treatments and row spacing. Hamid et al. [30] and Wang et al. [31] reported that 'Desi' cotton produced taller plants compared to American cotton. The difference among cotton types for plant height might be due to their genetic potential and plant's tendency to adjust according to available spacing [32].

Both cotton types produced a higher number of monopodial and sympodial branches  $\text{plant}^{-1}$  under recommended row spacing compared to UNRS under all weed control treatments. This might be due to better circulation of solar radiation in recommended row spacing where plants intercepted more energy, whereas UNRS reduced the number of monopodial and sympodial branches due to severe competition for nutrients, water and solar energy. A higher number of sympodial branches was indicative of the formation of more fruiting points. Ali et al. [33], Khan et al. [32] and Hamid et al. [30] reported the same results.

The total number of bolls produced by a plant is an important yield component having the greatest influence on seed cotton yield. A higher number of flowers and bolls  $\text{plant}^{-1}$  was recorded under recommended row spacing compared to UNRS because of ample space available for growth, photosynthetic efficiency, frequent availability of water and nutrients, less humidity for efficient control of insect pest infestation and saving bolls from rotting, which resulted in an increased number of flowers and bolls  $\text{plant}^{-1}$  (Table 4). A higher number of flowers and bolls  $\text{plant}^{-1}$  was observed in 'Desi' cotton than in American cotton under both row spacings with the same trend in all treatments (Table 4). Similar results were reported by Blaise et al. [10] and Singh [21]. The number of flowers and bolls  $\text{plant}^{-1}$  for both cotton types were significantly higher in a weed-free environment against weedy-check that might be due to weeds' competition for available resources. Similar results were reported by Nalini et al. [7] and Brodrick et al. [17].

A higher yield in UNRS was the direct result of higher plant density and number of bolls  $\text{m}^{-2}$  as compared to recommended row spacing even having a greater number of bolls  $\text{plant}^{-1}$ . This higher plant density in UNRS compensated the lesser number of bolls  $\text{plant}^{-1}$  and produced a greater number of bolls per unit area (Table 5). Our results were similar to Adams et al. [34], Hamid et al. [30], Singh et al. [11], Brodrick et al. [17] and Naim et al. [35]. Likewise, 'Desi' cotton produced a higher seed cotton yield under both row spacing as compared to American cotton which might be due to its better genetic potential. Moreover, it had a higher number of branches, flowers and bolls  $\text{plant}^{-1}$  as compared to American cotton (Tables 4 and 5). Similar results were reported by Blaise et al. [10] and Singh [21].

The seed cotton yield was significantly higher for both types in weed-free treatment due to less competition for available resources such as light, water, nutrients, and space (Table 5). Similar results were reported by Nalini et al. [7] and Brodrick et al. [17] in relation to weeds interference. Moreover, weed control at 30 DAS is more beneficial for both cotton types compared to the rest of the weed control treatments included in the study (Tables 4 and 5).

Allelopathy is another phenomenon involved in weed control. Several crops exhibit an allelopathic effect against weeds [36,37]. The differences among cotton types in weed-suppression ability are owed to their allelopathic potential. Several earlier studies have reported the allelopathic effect of different crops on the weeds identified in the current study [38,39]. The allelopathic effect of the mulches obtained from transgenic and non-transgenic cotton significantly affected weed dynamics and soil properties in different crops [40]. However, the allelopathic effect of the cotton types was not investigated in the current study; thus, it warrants further investigation.

## 5. Conclusions

American cotton is a crop of foreign origin and has great potential to produce seed cotton yield, whereas ‘Desi’ cotton is an indigenous species and well adapted to Asiatic conditions. The weed-free condition produced the highest seed cotton yield and the lowest weed infestation followed by weed control at 30 DAS. The 30 DAS is critical time to control weeds in cotton which would result in a higher seed cotton yield. Among cotton types, ‘Desi’ cotton presented lower weed infestation as compared to American cotton. Ultra-narrow row resulted in higher seed cotton yield of both cotton types. Overall, sowing cotton in ultra-narrow row spacing and controlling weeds at 30 DAS would result in lower weed infestation, higher seed cotton yield and economic returns.

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