Pak. J. Bot., 43(4): 1971-1983, 12011.

SUSTAINABLE COTTON PRODUCTION AND WATER ECONOMY THROUGH DIFFERENT PLANTING METHODS AND MULCHING TECHNIQUES

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Abstract

Planting methods and mulching techniques are important factors which affect crop growth, development and yield by conserving soil and plant moisture. A multifactorial experiment was conducted to study the water economy involving different planting methods and mulching techniques in cotton (*Gossypium hirsutum* L.) for two consecutive years (2004 and 2005) at the Agronomic Research Station, Khanewal. Two moisture stress tolerant cotton varieties (CIM-473 and CIM-499) were planted using four different planting methods i.e. 70cm spaced single row planting, 105 cm spaced double row strip planting, 70cm spaced ridge planting and 140 cm spaced furrow beds (or bed and furrows) along four mulching practices i.e. cultural, straw, sheet and chemical for their individual and interactive effects on various parameters including water use efficiency. Positive interactive effects of furrow bed planting method (140 cm spaced) with plastic sheet/film mulching were observed for all the parameters i.e., highest seed cotton yield (3009 and 3332 kg ha^{-1}), maximum water saving (up to 25.62% and 26.53%), highest water use efficiency up to 5.04 and 4.79 [µmol (CO_2)/mmol (H_2O)], highest net income (Rs. 27224.2 and 50927.7 ha^{-1}) with a cost-benefit ratio of 1.64 and 2.20 followed by maximum net income (Rs. 27382.2 and 47244.5 ha^{-1}) with 1.64 and 2.10 cost-benefit ratio in case of plastic mulch and 2814 and 3007 kg ha^{-1} in ridge planting method during 2004 and 2005, respectively. It is concluded that cotton crop can be grown using bed and furrow planting method with plastic sheet/film mulching technique for sustainable cotton production and better water economy.

Introduction

Drought or water deficit is one of the major abiotic stress limiting the productivity of agricultural crops. Cotton crop has been classified as a drought tolerant (Keith *et al*., 1994) crop and can tolerate moderate salinity present in the soil or in the irrigation water if drainage is adequate. It requires 620mm (Khan, 2001) or 600-800 mm (Saeed, 1994) of water either provided by rainfall or irrigation for proper growth and development during the growing season. It responds well to sufficient water by producing yields proportional to rainfall and supplemental irrigation water (Keith *et al*., 1994).

The increasing trend of water shortage during the last few years due to less rainfall and high temperature poses a serious threat to the cotton productivity. It is, therefore, very important to explore new strategy to cope with this hazardous problem. The economic and efficient use of water is one of the best ways to tackle this problem. Planting methods are important factors which affect crop growth, development and yield. Furrows and alternate furrow irrigation system (Flat planting, every row and alternate row earthing up) have been reported to save up to 50% irrigation water and enhance seed cotton yield as compared to flood irrigation system (Flat planting with no earthing up) (Wiese *et al.,* 1994). Production of 70-80 and 25 pounds of lint per inch of water applied has been reported by the furrow-irrigated system and the drip irrigation system, respectively (Norton *et al.*, 2001). It has also been reported that the maximum water saving and highest seed cotton yield was produced by the bed (raised bed) planting method (Anon., 2006).

Mulching is one of the important management options for conserving soil and plant moisture. It encourages better plant growth and development by conserving moisture, lowering soil temperatures around the roots zone, preventing erosion and reducing weed growth. Mulches can be derived from either organic or inorganic materials or a cover crop can also act as mulch. Higher yields associated with cover crops (a sort of bio mulch) in dry years was reported due to the increased infiltration of rainfall, less evaporation of moisture, increased organic matter and reduced soil compaction (Keith *et al*., 1994). An increase of 35% lint yield was observed in wheat stubble mulched plots than without stubbles and it was observed that Et (Evapotranspiration) water use efficiency was increased by the wheat stubble residue without additional input of water (Robert *et al.*, 2000).

There is a need to utilize available water in an efficient way. Information is lacking regarding the systematic work undertaken to evaluate various sowing/planting methods in combination with other practices of water conservation viz., use of various kinds of mulches with special reference to water use efficiency. Therefore, the present study was planned to evaluate the most suitable method of planting of cotton crop under different kinds of mulching practices for water savings/economy.

Materials and Methods

Experiments were conducted for two consecutive years (2004 and 2005) at Agronomic Research Station, Khanewal. Two cotton varieties, CIM-473 and CIM-499 were planted in 2nd fortnight of May, during the year 2004 and 2005, using four different planting methods viz., 70 cm spaced single row planting (P_1), 105 cm spaced double row strip planting (P_2), 70 cm spaced ridge planting (P_3) and 140 cm spaced furrow beds (or bed and furrows) (P_4) along with four mulching practices i.e. cultural (M_1), straw (M_2), plastic sheet (M_3) and chemical (M_4) for their individual and interactive effects on various parameters including Water Use Efficiency. The trials were laid out in randomized complete block design with factorial arrangement in a plot of size 9 m × 6 m. As far as mulching practices are concerned, in case of cultural mulch (M_1), four hoeing, 2 dry and 2 in '*water*' condition after 1st and 2nd irrigation were applied to create cultural mulch for moisture conservation and eradication of weeds. Straw mulch (M_2) was applied as 5 cm thick layer of rice straw after complete germination of cotton seed in each plot as per treatment. In case of M_3, the polyethylene sheet/film was spread between rows after completion of germination. In chemical mulch (M_4), the foliar spray of methanol @ 30% (v/v) was applied, a total of 150 liters spray solution per hectare. The spray was applied on July 15th, August 1st, August 15th and August 31st between 10.00 a.m. to 12.00 noon during bright sunny days. The treatments were planned to coincide with first square appearance and fortnightly after the appearance of first square as a total of 4 applications. Crop was sprayed with knapsack sprayer using two nozzles per row and operated at a speed of 4 km per hour using 275 kPa pressure to deliver 150-litre ha^{-1} (Makhdum *et al*., 2002).

First irrigation was applied to P_1 and P_2 at 35 days after planting and P3 and P4 were irrigated just after seeding stage. The subsequent irrigations were applied to all treatments as per need of the crop by observing the physical appearance of the plants i.e. dull green color of leaves, wilting appearance and reddish color of stem near flag leaves uniformly. Measured quantity of irrigation water was applied each time by using cut throat flume method. Data were recorded and water saving percentage was calculated in case of various planting methods against P1 (70 cm spaced single row flat planting). Observations on the following parameters were recorded during the course of study.

Total dry weight: The above ground portion of the plants was removed at six growth stages i.e., 45, 60, 75, 90, 105 and 120 days after sowing (DAS), from one square meter area in the sub-plot reserved for destructive plant sampling. The plants were partitioned into leaves, stems and fruiting forms according to method of Mullins & Burmester, 1990 and fresh weight was determined. A sub sample of 110g was taken from the whole fresh material consisting of various plant parts i.e., leaves, branches, flowers, stalk etc. The sub sample was placed in a forced-draft oven and dried at 70°C to a constant weight. Dry weight was estimated on per unit land area basis according to method described by Wells & Meredith, 1984.

Relative growth rate: The following formulae were used to calculate relative crop growth rate at 60, 75, 90, 105 and 120 DAS as described by Hunt (1978):

$$\text{Relative Growth Rate } (g\ g^{-1}\ d^{-1}) = (\log_e W_2 - \log_e W_1) / (t_2 - t_1)$$

where $\log_e W_1$ and $\log_e W_2$ are the values of total dry weights at times t_1 and t_2, respectively

Net photosynthesis (P_N) and transpiration rate (E): The instantaneous measurements of net photosynthetic rate (P_N) and transpiration rate (E) were made on fully expanded youngest leaf of 10 plants (4th leaf from top) using an open system portable infra red gas analyzer ADC-LCA 4 (Analytical Development Company, Huddleston, England). Measurements were performed on 60 days old plants at 11:00 AM with the following conditions: molar flow of air per unit leaf area (408.5 mmol m^{-2} s^{-1}), atmospheric pressure (97.8 kPa), water vapor pressure inside chamber (1120-1220 Pa), photosynthetic active radiation at leaf surface was maximum (up to 1280 μmol m^{-2} s^{-1}), temperature of leaf was maximum up to (34.4 °C), ambient temperature (32.3-37.9°C) and ambient CO_2 concentration (351.3 μmol mol^{-1}).

Water-use efficiency (WUE): Data for Water-Use Efficiency (WUE) were computed by the following equation as mentioned by Makhdum (2003):

$$\text{WUE} = \text{Net photosynthetic rate } (P_N) / \text{Transpiration Rate } (E)$$

where

WUE = Water-Use Efficiency (μmol CO_2/ mmol H_2O)

P_N = Net photosynthetic rate (μmol CO_2 m^{-2} s^{-1}) and

E = Transpiration rate (mmol H_2O m^{-2} s^{-1})

Plant height: Plant height of five randomly selected plants was measured at maturity and the mean height was calculated.

Leaf area index: The leaf area index was computed using following formula

$$\text{Leaf area index} = \text{Leaf area} / \text{Land area}$$

Number of bolls per plant: Data on number of bolls $plant^{-1}$ was recorded from 10 randomly selected plants from each treatment at maturity and then the total bolls were averaged as boll number per plant.

100-Boll weight: 100 bolls from each plot were picked randomly, sun dried and weighed.

Seed cotton yield: The seed cotton was hand picked at the end of season from each plot, weighed and then calculated on per hectare basis.

Biological yield: For recording vegetative dry biomass data, cotton plants in each plot were cut 1 inch below ground level and left in the field for sun drying. After complete drying, the total weight per plot was recorded and then converted into vegetative dry biomass in kg ha^{-1} as under:

$$\text{Biological yield} = \text{Vegetative dry biomass} + \text{Seed cotton yield}$$

Harvest index: The harvest index was calculated by using the following formula:

$$\text{H.I.} = \text{Seed cotton yield} / \text{Biological yield} \times 100$$

Total water applied: Irrigation water applied to each plot was recorded with the help of cut throat flume and the quantity was calculated by using formula:

$$Qt = Ad \text{ or } t = Ad/Q$$

where

Q is the discharge of water

A is the area

D is the depth of irrigation water

T is time taken

Quantity of water saved: From the data of applied irrigation water, the quantity of water saved in case of each planting method was calculated.

Economic analysis: The economic analysis, cost of production and gross income for cotton crop was calculated. Net income was worked out by deducting the cost of production from the gross income (CIMMYT, 1988 An Economics Training Manual). Cost Benefit Ratio was worked out by dividing gross income ha^{-1} with total cost involved ha^{-1}.

Statistical analysis: The recorded data were statistically analyzed by using Fisher's analysis of variance techniques and least significant difference (LSD) at 5% probability level was applied to compare the differences among the treatment means (Steel *et al*., 1997).

Results and Discussions

Leaf area index: A significant effect of cotton genotypes and different planting methods on leaf Area Index (LAI) was demonstrated during both the years of study (Fig. 1 a-f). Periodically a linear increase was observed up to 90-100 days after sowing (DAS) and then decline with the passage of time up to 120 DAS for these two factors. The trend was similar for both the years. A linear increase and then decline in LAI of cotton after 90-100 DAS was most probably due to leaves senescence at crop maturity. The mulching practices had not any significant effect on leaf area index of cotton crop (Fig. 2 g-l) but a linear increase was observed as in case of genotypes and planting methods. Randall *et al*., 1997 used Leaf Area Index (LAI) as a measure of determining the growth rate and crop yield. The most critical time for cotton leaf growth was observed to occur between 40 and 65 days after sowing, which coincides with early flowering. The results also got support from the findings of Dagdelen *et al*., 2006 who grew cotton and corn crops and observed that leaf area index (LAI) and dry matter yields (DM) showed an increasing trend with increasing water use for both treatments. While Gul *et al*., 2009 reported that the highest leaf area $plant^{-1}$ and leaf area index in the hand weeding and black plastic mulch might be attributed to their weed control, thus providing favorable conditions. Plastic mulches have the potential to accelerate vegetative growth.

Relative growth rate: The physiological processes i.e., crop growth rate, relative growth rate, leaf area duration and leaf area ratio are products of photosynthesis. Mauney (1986) reported that these indices of agricultural productivity are greatly affected by light, temperature, mineral nutrients and moisture. Periodical data regarding relative growth rate (RGR) at 45 to 120 days after sowing with 15 days interval, of all the treatments (planting methods and mulching practices) for both the years 2004 and 2005 are presented in Fig. 2 g-l. The impact of planting methods and mulching practices on RGR of two cotton was significant during both the years. Planting method of 105cm spaced double row during 2004 and 2005 gained significantly the maximum RGR (0.0147 and 0.0140 $g\ g^{-1}d^{-1}$, respectively), followed by 70 cm single row planting (0.0130 $g\ g^{-1}d^{-1}$) during 2004 and bed and furrow planting (0.0112 $g\ g^{-1}d^{-1}$) during 2005 at 120 days after sowing (DAS). In case of mulching practices, during the year 2004 significantly higher RGR (0.0127 $g\ g^{-1}d^{-1}$) was gained by the plots where the crop was planted under rice straw mulch and under cultural mulch (0.0126 $g\ g^{-1}d^{-1}$) during 2005 at 120 DAS. Having a glance on the data, a gradual decrease in RGR up to 105 DAS and then at a constant rate up to 120 DAS approaching to maturity was revealed. It was also observed that relatively higher RGR was maintained by cotton variety CIM-473 than by CIM-499 (Fig. 1 g-l).

Plant height at harvest: Significant impacts of genotypes, planting methods and mulching practices on plant height were observed during both the years of study 2004 and 2005 (Table 1). The cotton cv. CIM-473 exhibited more plant height (152.02 cm and 150.06 cm) as compared to CIM-499 (145.7 and 143.7 cm) during the years 2004 and 2005, respectively. Infact, varietal appearance of CIM-473 was a long statured and CIM-499 was medium to long stature, erect growing variety with sympodial bearings.

Crop planted on 70 cm spaced ridges attained more height of 159.8 cm and 161.9 cm followed by 146.8 cm and 151.8 cm under with bed and furrow method during 2004 and 2005, respectively. The interaction between planting method and genotypes was found statistically significant only during 2004. Cotton cultivar CIM-473 attained maximum height of 161.0 cm under ridge sowing, being statistically at par with bed and furrow planting. The cotton cultivar CIM-499 was also statistically at par with CIM-473 which gave 158.5 cm plant height when planted on 70 cm spaced ridges (Table 1).

As regards mulch treatments, plant height under plastic sheet mulching was significantly higher (155.5 cm and 153.8 cm) compared to other treatments except cultural mulching which was statistically at par having plant height 153.1 cm and 150.2 cm during 2004 and 2005, respectively (Table 1). It indicated that more moisture was conserved under plastic sheet and cultural mulch providing more water to cotton throughout the growing period. The lowest plant height (139.9 cm and 138.1 cm) was recorded under straw mulch treatment during both the years of study (Table 1). The interaction of the mulching practices with other factors under study was found non-significant.

Methanol foliar spray, a chemical mulching in this study, significantly increased cotton plant height and shoot/root ratio etc. The increase in plant height was attributed to increase in node number on the main stem in consequence of methanol application. Significant increase in plant height of cotton by the foliar applications of methanol was also reported by Barnes & Houghton (1994). But increase in main stem height owing to higher photosynthetic rate of cotton in mulched plots and increased soil water content was also observed and is in line with the findings of ZongBin *et al*., 2004. Plant height, fresh and dry biomass of tomato plant was increased with application of mulches (Saeed & Ahmad, 2009).

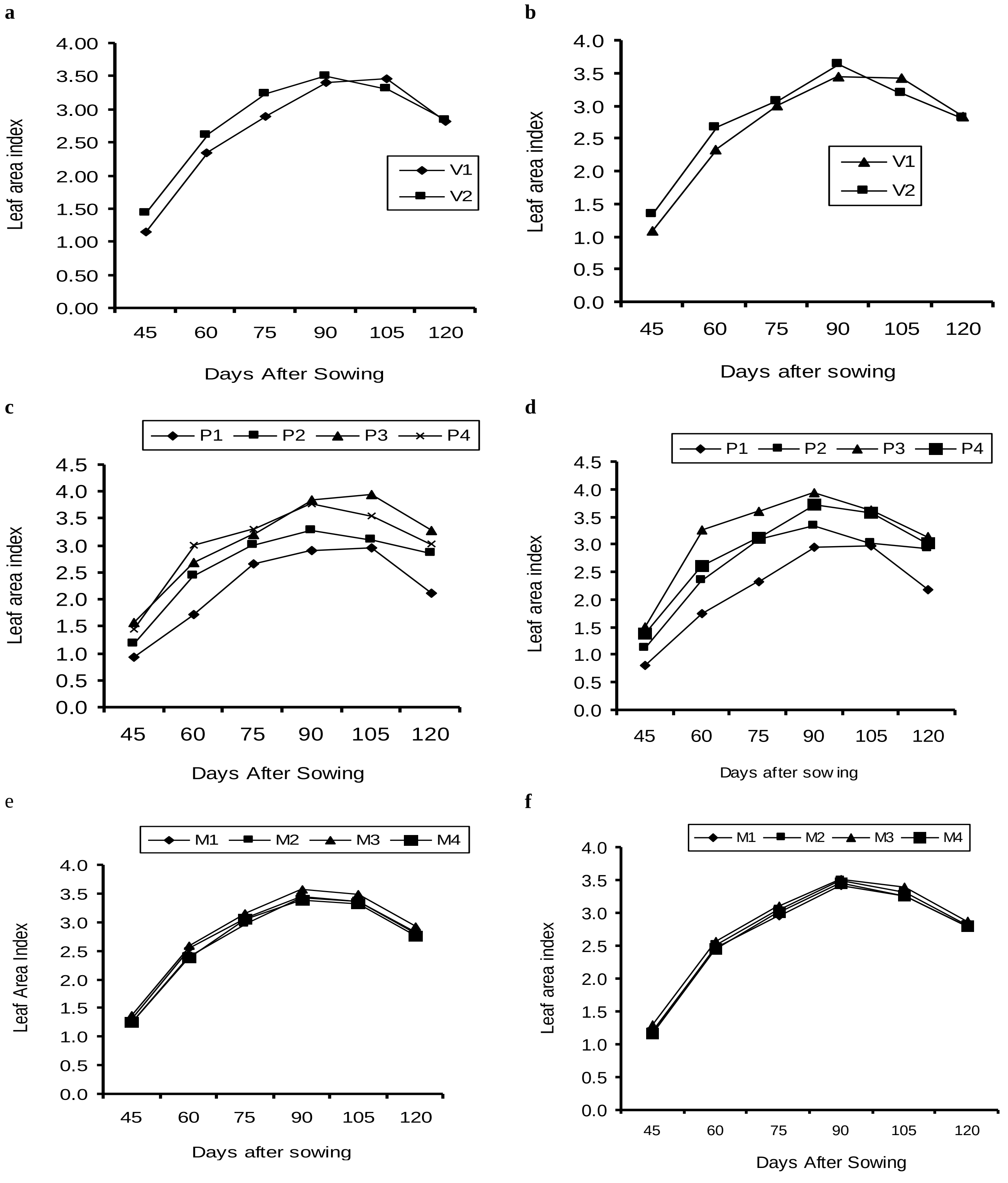

Fig. 1. Leaf Area Index of two different cotton genotypes during the year 2004 (a) and 2005 (b), LAI affected by different planting methods during the year 2004 (c) and 2005 (d), LAI affected by different mulching types during the year 2004 (e) and 2005 (f).

Bolls per plant: Significant impact of planting methods and mulching materials on number of bolls $plant^{-1}$ of two cotton varieties was observed during 2004 and 2005. The cotton cultivar CIM-499 presented higher number of bolls $plant^{-1}$ (28.4) compared to CIM-473 (26.1) during both the years of study (Table 1). The interaction with other study factors was almost non-significant during both the years.

As regards planting methods, the highest number of bolls of 30.2 and 33.3 was produced under bed and furrow planting method during 2004 and 2005, respectively. It perhaps was due to relatively more plant growth and more number of sympodial branches per plant because of better water availability to cotton plants. The lowest number of bolls per plant was observed in plots planted at 105 cm spaced double row with 24.3 and 27.0 boll number during 2004 and 2005, respectively (Table 1). Similar findings were reported by Khalid *et al*., (1999). On the contrary, Javed (1996) reported that number of bolls per plant and boll weight per plant was not affected significantly by planting patterns.

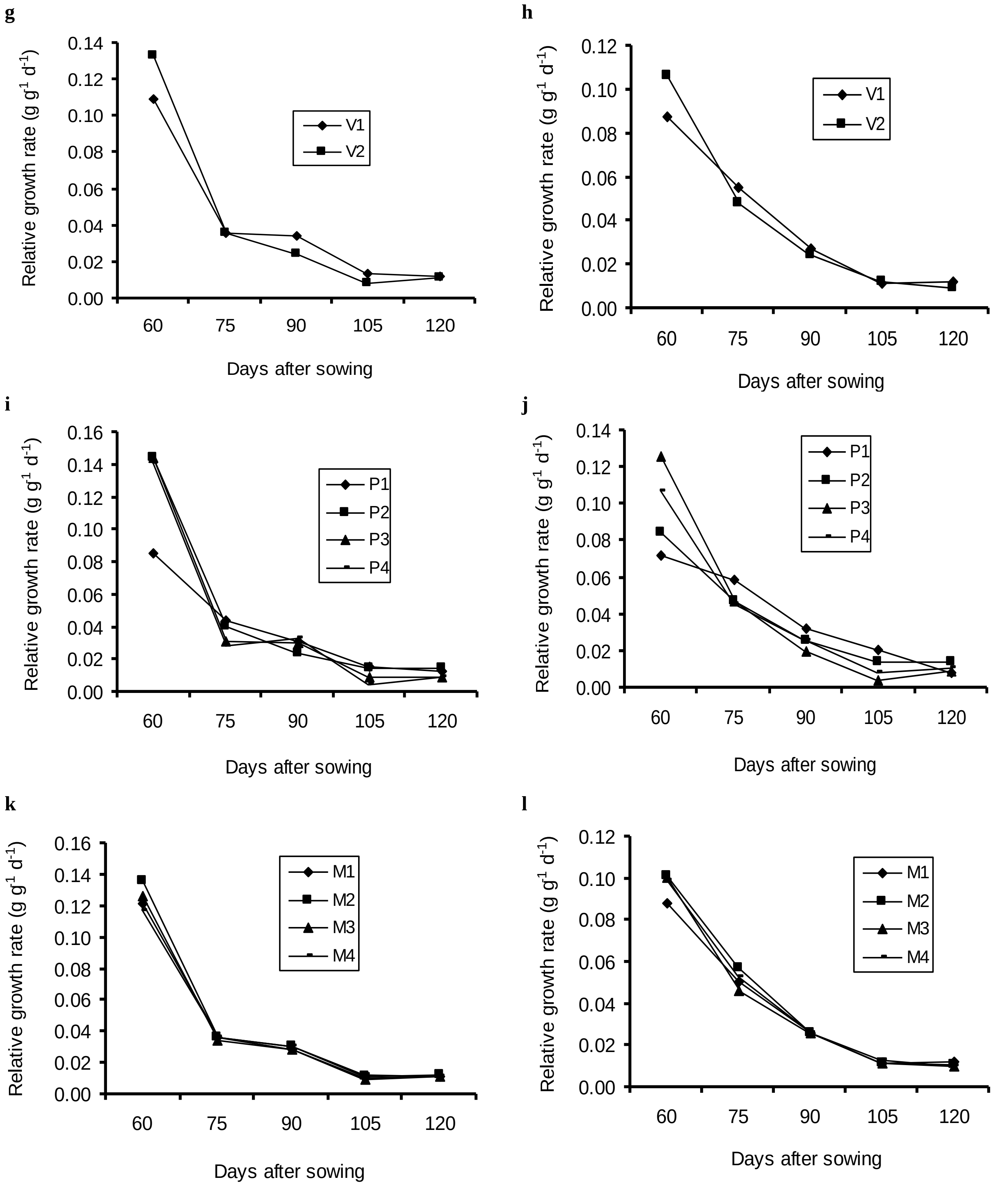

Fig. 2. Relative Growth Rate of two different cotton genotypes during the year 2004 (g) and 2005 (h), RGR as affected by different planting methods during the year 2004 (i) and 2005 (j), RGR as affected by different mulching types during the year 2004 (k) and 2005 (l).

The impact of mulching practices on the number of bolls per plant was also significant during both the years of study. The highest number of bolls (30.6 and 32.8) per plant was demonstrated by the plots mulched with plastic sheet during 2004 and 2005, respectively. It showed that plastic sheet mulch is more effective in conserving the soil moisture than rest of the mulching practices under study.

The interaction of planting methods and mulching practices was significant only during 2004. Three interactions, 70 cm spaced single row planting × plastic sheet mulching, bed and furrow planting × plastic sheet mulching and 70 cm spaced single row planting × cultural mulching, yielded greater number of bolls per plant (Table 1). The lowest number of bolls per plant were recorded where 70 cm spaced ridges × rice straw mulching was implemented. Similar results were reported by Abdel (1998) and ZongBin *et al*., (2004).

Table 1. Impact of planting methods and mulching material on growth and yield attributes of two cotton varieties.

Varieties (V)	**Plant height (cm)**		**Boll number plant^{-1}**		**100-Dry boll weight (g)**		**Seed cotton yield (kg ha^{-1})**	
	2004	**2005**	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**
V_1 = CIM 473	152.021	150.063	26.1	29.552	308.875	320.23	2701.2	2854.35
V_2 = CIM 499	145.688	143.688	28.4	30.019	313.063	308.42	2829.1	3022.43
LSD at 5%	4.3435	4.3631	0.83	NS	NS	9.20	6.95	86.04
Planting methods (P)								
P_1 = 70cm spaced single row	140.6 c	131.6 d	28.6 b	30.50 b	317.0 ab	318.8ab	2713 b	2857.0 c
P_2=105cm spaced double row	148.3 b	142.3 c	24.3 d	27.00 c	295.8 c	304.29b	2525 c	2558.0 d
P_3 = 70cm spaced ridges	159.8 a	161.9 a	25.96 c	28.35 c	303.3 bc	309.21b	2814 b	3007.0 b
P_4=140cm spaced furrow beds	146.8 bc	151.8 b	30.20 a	33.29 a	327.8 a	325.0 a	3009.0a	3332.0 a
LSD at 5%	7.348	7.381	1.405	1.469	14.84	15.56	136.6*	145.6
Mulching materials (M)								
M_1 = Cultural mulch	153.1 ab	150.2ab	29.47 a	31.80 a	318.2 ab	320.0ab	2891 b	3127.0 a
M_2 = Straw mulch	139.9 c	138.1 c	22.78 c	26.24 c	293.4 c	293.9 c	2448 d	2569.0 c
M_3 = Sheet mulch	155.5 a	153.8 a	30.62 a	32.83 a	327.5 a	333.3 a	3040 a	3220.0 a
M_4 = Chemical mulch	146.9 bc	145.5bc	26.19 b	28.28 b	304.8 bc	310.0 b	2683 c	2837.0 b
LSD at 5%	7.348	7.381	1.40	1.47	14.84	15.56	136.60	145.60

Any two means not sharing a letter in common differ significantly at $p<0.05$

Dry boll weight: The impact of planting methods and mulching materials on dry boll weight (100 boll weight) showed significant effects on two cotton varieties during 2004 and 2005. Among cotton varieties, CIM-473 produced heavier bolls than CIM-499 on an average (Table 1).

Regarding planting methods, the highest values of 327.8 g and 325.05g were recorded when crop was sown under bed and furrows during 2004 and 2005, respectively. The lowest dry boll weight of 295.8g and 304.29g was obtained in 105 cm spaced double row planting in both the years. These results are in contrast with those of Javed (1996) and Teama *et al.*, (2000) who reported that boll weight and boll number per plant were not affected significantly by the geometry of planting. However, a glance on the data reflected a comparatively better boll weight in case of bed and furrow planting method than others that probably due to the better moisture management practices resulting in better water use efficiency and good return (McAlavy, 2004).

In concern with mulching practices, the highest dry boll weight was recorded under plastic sheet mulching with 327.5 g and 333.3 g 100-dry boll weights during 2004 and 2005, respectively. The lowest dry boll weight (293.4 g and 293.9 g) was recorded under crop mulched with rice straw during both the years (Table 1). The results are in line with those of ZongBin *et al*., (2004). The interactions among different factors in study were statistically non-significant.

Seed cotton yield: The data regarding seed cotton yield revealed a statistically significant yield response to individual factors for both the years, while their interactions remained non-significant (Table 1). Among cotton genotypes, higher weights of 2829 and 3022 kg ha^{-1} were recorded in case of CIM-499 as compared to 2701 and 2854 kg ha^{-1} for CIM-473 during 2004 and 2005, respectively. The results are in agreement with Khan *et al.*, (2010), Gerik *et al*., (1996) and Pace *et al*., (1999).

The highest seed cotton yield of 3009 and 3332 kg ha^{-1} was recorded in bed and furrow planting method followed significantly by 2814 and 3007 kg ha^{-1} in ridge planting method during 2004 and 2005, respectively. This may be due to better utilization of irrigation water with better management practices and availability of sufficient moisture to cotton plant at critical stages which resulted in better produce as well as the saving of irrigation water. Similar results were reported by Madiwalar & Prabhakar (1998). Cotton planted by 105 cm/30 cm spaced double row, registered the lowest seed cotton yield of 2525 and 2558 kg ha^{-1} during 2004 and 2005, respectively. Javed (1996**)** and Anon., (2006) confirmed that seed cotton yield was significantly affected by planting methods. While Teama *et al.*, (2000), Chaudhari *et al*., (2001) and Akhtar *et al.*, (2003**)** negated by reporting that seed cotton yield was not significantly affected by the sowing methods. Moreover, Ghadage *et al*., (2005) were of the view that growth, seed cotton yield and the economics were not influenced by planting patterns and irrigation techniques.

As regards mulching techniques, the highest seed cotton yields of 3040, 3220 and 3127 kg ha^{-1} were received from plastic sheet mulched cotton crop during 2004 and 2005 and cultural mulch during 2005, respectively. The lowest values (2448.0 and 2569 kg ha^{-1}) of seed cotton yield were obtained in straw mulch in both the years. The results were supported by the findings of Abdel (1998), ZongBin *et al*., (2004) and Ghadage *et al*., (2005). Subrahmaniyan & Kalaiselvan (2005) observed that the polyethylene film mulch indicated that the pod yield was also highest as 26.17 and 26.46 q ha^{-1}. Sampathkumar *et al*., (2006) reported that the highest seed cotton yield (2430 kg ha^{-1}) and water use efficiency (3.53 kg ha^{-1} mm^{-1}) were recorded under rice straw mulch at 5 t ha^{-1} over no mulching.

Thus it is concluded that bed and furrow and ridge planting method not only save irrigation water but also enhance cotton productivity through conducive environments. The mulching practices not only conserve soil moisture, but restrict weed growth as well, thus helping in the enhancement of ultimate yield of the crop.

Biological yield: The data presented in Table 2 regarding biological yield revealed that varietal response to biological yield was non-significant while planting methods and various mulching techniques responded significantly during the two years of study. The interaction of all the factors under study was non-significant. Although the biological yield of the two cotton genotypes was statistically non-significant, yet cotton cv. CIM-473 produced comparably more biological yield (Table 2).

Table 2. Impact of planting methods and mulching material on growth and yield attributes of two cotton varieties.

Genotypes (V)	Biological yield (Kg ha^{-1})		Harvest Index (%)		Net photosynthetic rate (P_N) (μ mol $m^{2}S^{-1}$)		Transpiration rate (E) (m mol of H_2O $m^{-2}S^{-1}$)		Water use efficiency (μ mol(CO_2)/m mol (H_2O)	
	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
V_1 = CIM 473	8756.313	9277.646	30.654	30.74	23.728	24.128	7.938	7.587	3.28	3.05
V_2 = CIM 499	8553.708	9125.604	33.108	33.29	24.631	25.379	7.616	7.147	3.67	3.32
LSD at 5%	NS	NS	0.7456	0.789	0.6976*	0.7200*	0.23	0.21	0.92	0.75
Planting methods (P)										
P_1=70cm spaced single row	8110.0 b	8541.0 b	33.40 a	33.7a	23.81 b	24.12 b	7.918 b	7.619 b	3.23 c	3.07 c
P_2=105cm spaced double row	8438.0 b	8517.0 b	30.06 b	30.0b	22.32 c	21.94 c	8.391 a	8.335 a	2.66 d	2.69 d
P_3=70cm spaced ridges	8995.0 a	10070.0 a	31.26 b	29.8b	24.57 b	25.24 b	7.653 b	7.153 c	3.60 b	3.26 b
P_4=140cm spaced furrow beds	9077.0 a	9683.0 a	32.80 a	34.4a	26.02 a	27.72 a	7.147 c	6.360 d	4.40 a	3.71 a
LSD at 5%	426.3	455.7	1.261	1.336	1.180	1.218	0.3806	0.3627	1.559	21.277
Mulching materials (M)										
M_1 = Cultural mulch	9020.0 a	9772.0 a	32.08ab	32.25	24.46 b	26.19 a	7.446 c	6.890 c	3.88 b	3.32 b
M_2 = Straw mulch	7845.0 c	8131.0 c	31.00 b	31.65	20.99 d	21.95 c	8.603 a	8.256 a	2.71 d	2.47 d
M_3 = Sheet mulch	9285.0 a	10040.0 a	32.75 a	32.054	28.53 a	26.88 a	7.066 c	6.662 c	4.11 a	4.08 a
M_4 = Chemical mulch	8471.0 b	8859.0 b	31.69ab	32.096	22.74 c	24.00 b	7.992 b	7.659 b	3.21 c	2.86 c
LSD at 5%	426.3	455.7	1.261	NS	1.180	1.218	0.3806	0.3627	1.559	1.277

Any two means not sharing a letter in common differ significantly at p< 0.

As regards planting methods, the cotton crop planted on bed and furrows and 70 cm spaced ridges significantly produced higher biological yields of 9077 and 8995 kg ha^{-1} during 2004 and 9683 and 10070 kg ha^{-1} during 2005, respectively. Rest of the planting methods (70 cm spaced single row and 105 cm spaced double row planting) yielded significantly low i.e., 8325 and 8477.5 kg ha^{-1}.

The response of biological yield to mulching practices was also found significant. The highest values of 9285 and 10040 kg ha^{-1} were recorded for plastic sheet mulch and 9020 and 9772 kg $ha^{-1}$for cultural mulch during 2004 and 2005, respectively. The straw mulched cotton crop documented the lowest biological yields of 7845 and 8131 kg ha^{-1} during 2004 and 2005, respectively (Table 2). Gul *et al*., (2009) reported that increased biological yield of maize in the hand weeding and black plastic mulch might be attributed to increase in plant height, maximum leaf area and leaf area index as well as lower fresh weeds biomass.

Harvest index: Data regarding harvest index of cotton crop are presented in Table 2 indicating statistically significant response of genotypes to planting methods during both the years of study, while different mulching practices had significant effect on harvest index value in the year 2004 only.

The higher harvest index was exhibited in case of CIM-499 (33.1% and 33.3%) than that of CIM-473 with 30.65% and 30.74% during 2004 and 2005, respectively. This trend seems due to variability in the genetic potential of the two genotypes. Stiller *et al*., (2005) reported that later maturing cultivars had higher harvest index.

Regarding the planting methods, bed and furrow and 70 cm spaced single row planting registered higher values for harvest index of 32.8% and 33.4% during 2004 and 34.45% and 33.73% during 2005, respectively as compared to other two planting methods i.e., paired row and ridge planting (Table 2).

The response of mulching practices was noted as statistically significant during 2004 while it was non significant in 2005. Higher values of harvest index were recorded in case of plastic sheet mulching (32.75%) while the lowest (31.0%) in straw mulching. The other mulching methods remained at par with 31.69% and 32.08% for chemical and cultural mulching treatment during 2004, respectively (Table 2). The findings were supported by the results of Shaozhong *et al.*, (2002). The clear benefits of extra moisture support the need to develop water conserving technologies such as reduce tillage or mulching through residue retention (Badaruddin *et al.*, 1999).

Net photosynthesis rate (P_N): The impact of all the factors under study on net photosynthetic rate (P_N) was observed significant during both the years of study as presented in Table 2. Cotton genotypes CIM-499 maintained higher rate of net photosynthesis as 24.631 and 25.379 (μmol m^{-2} s^{-1}) compared to CIM-473 (23.728 and 24.128 μmol $m^{-2}s^{-1}$) during 2004 and 2005, respectively. The results are in line with Gerik *et al*., (1996), Pace *et al*., (1999) indicating that CIM-499 yielded more than that of CIM-473 because of having greater photosynthetic activity. Among methods of planting cotton bed and furrow method demonstrated higher rates of P_N as 26.02 and 27.72 μmol $m^{-2}s^{-1}$ during 2004 and 2005 respectively. The lowest P_N was exhibited in case of 105 cm spaced double row planting (22.32 and 21.94 μmol $m^{-2}s^{-1}$) during both the year of study.

Mulching practices responded significantly to P_N during both the years of study. The highest P_N of 28.53 and 26.88 (μ mol $m^{-2}S^{-1}$) and the lowest P_N 20.99 and 21.95 (μmol $m^{-2}s^{-1}$) were observed with plastic sheet mulch and rice straw mulch during 2004 and 2005, respectively (Table 2). The interactions were non-significant among all the study factors. The findings with lowest P_N rate in case of rice straw mulch do not get support by the results of ZongBin *et al*., (2004) who reported higher photosynthetic rate of cotton in wheat straw mulched plots. The results of this study also indicate that crop might have experienced more stress in 105 cm double row planting method and in rice straw mulched plots. The transpiration rates were also higher under these treatments, thus resulting in reduced P_N rates. The results are in line with that of Basal *et al*., (2005). No significant interaction among the factors was recorded for this parameter.

Transpiration rate (E): The data on transpiration rate (E) presented in Table 2 demonstrated significant variations among means of different factors under study. The cotton genotypes exhibited significant response to transpiration rate during both the years of study. The highest transpiration rates of 7.938 and 7.587 mmol. of H_2O m^{-2} s^{-1} were maintained by cotton genotype CIM-473 (during 2004 and 2005). CIM-499 maintained transpiration rate (E) of 7.62 and 7.15 (mmol. of H_2O m^{-2} s^{-1}) during 2004 and 2005, respectively.

The impact of different planting methods on transpiration rate (E) was also found significant during both the years of study. The highest transpiration rate (E) was found in case of cotton crop planted in 105 cm spaced double rows with E of 8.391 and 8.335 (mmol. of H_2O m^{-2} s^{-1}), while the lowest E was recorded as 7.147 and 6.360 (mmol of H_2O m^{-2} s^{-1}) in case of bed and furrows planting method during 2004 and 2005, respectively. As indicated in the data the higher transpiration rate in 105cm spaced double row planting may be due to wider row spacing, resulting in free wind movement etc., while low transpiration rate may be due to the effect of plant canopy micro climate on CO_2 concentrations etc. The results are in agreement with those of Basal *et al*., (2005) who stated that among the important morpho-physiological traits relating to drought tolerance in cotton; also include reduced transpiration, stomatal conductance and photosynthetic rate (Nepomuceno *et al*., 1998). The findings are in consonance with those of Kumar *et al*., (2001) who reported significant decrease in transpiration rate (E), stomatal conductance (g_s), carboxylation efficiency (CE) and water potential (Psi W) with increasing water stress. However, water use efficiency (WUE) was unaffected.

Different mulching practices also exhibited significant response to transpiration rate (E) during 2004 and 2005. The highest transpiration rate (E) was recorded in rice straw mulched plots as 8.603 and 8.256 (mmol of H_2O $m^{-2}s^{-1}$) while the lowest E (7.066 and 6.662) in plastic sheet mulch and statistically at par with cultural mulch (7.446 and 6.890) during 2004 and 2005, respectively. The interaction of all the factors under study was found non-significant (Table 2).

Water use efficiency: The data presented in Table 2 revealed that the impact of planting methods and mulching materials on water use efficiency (WUE) of two cotton varieties were significant during both the years of study. Cotton variety CIM-499 registered the highest water use efficiency of 3.67 as compared to 3.28 [µmol (CO_2)/mmol (H_2O)] of CIM 473 during 2004. Similar trend was recorded in 2005. The highest water use efficiency was recorded when crop was planted on bed and furrow with 4.40 and 3.71 [µmol (CO_2)/mmol (H_2O)], while the lowest values of water use efficiency were recorded in case of 105 cm spaced double row planting with 2.66 and 2.69 [µmol (CO_2)/mmol (H_2O)] during 2004 and 2005, respectively.

As regards mulching practices, the highest water use efficiency 4.11 and 4.08 [µmol (CO_2)/mmol (H_2O)] was reflected in case of plastic sheet mulch while the lowest WUE i.e., 2.71 and 2.47 [µmol (CO_2)/mmol (H_2O)] was documented when crop was mulched with rice straw, during 2004 and 2005, respectively (Table 2).

As far as the interactions are concerned, it was observed that all factors under study interacted significantly during both the years of study. In case of genotypes × mulches, it was observed that highest WUE [4.33 and 4.28 µmol (CO_2)/mmol (H_2O)] was registered under CIM-499 × plastic sheet mulch treatment while the lowest water use efficiency was recorded in case of CIM-499 x rice straw mulch with 2.87 and 2.55 [µmol (CO_2)/mmol (H_2O)] during 2004 and 2005, respectively (Table 3). The interaction of genotypes × planting method revealed that CIM-499 × bed and furrow interaction gave highest WUE of 4.61 and 3.94 [µmol (CO_2)/mmol (H_2O)] during 2004 and 2005 while the lowest values 2.80 [µmol (CO_2)/mmol (H_2O)] were recorded in CIM-499 × 105 cm spaced double row planting during 2004 and 2.59 [µmol (CO_2)/mmol (H_2O)] in case of CIM-473 × 105 cm spaced double row planting, during 2005 (Table 3).

Table 3. Interactive effect of planting methods × mulches on number of bolls per plant of two cotton genotypes.

Water use efficiency (µ mol(CO_2)/m mol (H_2O)					
Genotypes (V) × Mulches (M)	**2004**	**2005**	**Genotypes (V) × Planting methods (P)**	**2004**	**2005**
($V_1 \times M_1$)	3.65 d	3.10 d	($V_1 \times P_1$)	2.99 f	2.97 e
($V_1 \times M_2$)	2.56 h	2.39 h	($V_1 \times P_2$)	2.53 h	2.59 g
($V_1 \times M_3$)	3.89 c	3.88 b	($V_1 \times P_3$)	3.41 e	3.15 d
($V_1 \times M_4$)	3.02 f	2.82 f	($V_1 \times P_4$)	4.20 b	3.48 b
($V_2 \times M_1$)	4.10 b	3.54 c	($V_2 \times P_1$)	3.48 d	3.17 d
($V_2 \times M_2$)	2.87 g	2.55 g	($V_2 \times P_2$)	2.80 g	2.79 f
($V_2 \times M_3$)	4.33 a	4.28 a	($V_2 \times P_3$)	3.80 c	3.37 c
($V_2 \times M_4$)	3.39 e	2.91 e	($V_2 \times P_4$)	4.61 a	3.94 a
LSD at 5 %	0.7799	0.6389	LSD at 5 %	0.7799	0.6389

Any two means not sharing a letter in common differ significantly at $p<0.05$

The interaction of planting method × mulches revealed that highest WUE was recorded when crop was planted on bed and furrows under plastic sheet mulching with 5.04 and 4.79 [µmol (CO_2)/mmol (H_2O)], while the lowest WUE was recorded in 105 cm spaced double row × rice straw mulch (2.11 and 2.13 [µmol (CO_2)/mmol (H_2O)] during 2004 and 2005, respectively). Similar trend was noted when averaged across the years (Table 6).

The three way interaction among genotypes × planting method × mulches revealed that highest water use efficiency was observed with 5.20 and 5.12 [µmol (CO_2)/mmol (H_2O)] in case of CIM-499 × bed and furrow planting × plastic sheet mulch during 2004 and 2005 respectively (Table 7), while the lowest WUE was recorded as 2.06 [µmol (CO_2)/mmol (H_2O)] for CIM-499 x 105 cm spaced double row × rice straw mulch) during 2004 and 1.87 [µmol (CO_2)/mmol (H_2O)] in case of CIM-473 × 105 cm spaced double row × rice straw mulch during 2005 (Table 7).

Table 4. Irrigation water applied/used and water saved in case of different planting methods.

Planting Methods	Total water applied (mm)		Quantity of water saved (%)	
	2004	2005	2004	2005
P_1 = 70cm spaced single row	630.0 a	646.8 a	-	-
P_2 = 105cm spaced double row	622.3 a	628.6 a	1.22	2.81
P_3 = 70cm spaced ridges	535.7 ab	515.9 b	15.00	20.24
P_4 = 140cm spaced furrow beds	468.6 b	475.2 b	25.62	26.53
LSD at 5%	100.6	111.7		

Any two means not sharing a letter in common differ significantly at $p<0.05$

Table 5. Interactive effect of genotypes (V) with mulches (M) and planting methods (P) on water use efficiency.

Number of bolls per plant		
Planting methods (P) × Mulches (M)	2004	2005
$P_1 M_1$	32.68 a	32.80
$P_1 M_2$	21.60 fg	26.65
$P_1 M_3$	33.40 a	33.90
$P_1 M_4$	26.67 cde	28.65
$P_2 M_1$	24.95 de	29.10
P_2M_2	21.67 fg	23.55
P_2M_3	26.55 cde	30.30
$P_2 M_4$	24.20 ef	25.05
$P_3 M_1$	28.13 cd	30.35
$P_3 M_2$	21.10 g	24.967
$P_3 M_3$	29.50 bc	31.50
$P_3 M_4$	25.10 de	26.60
$P_4 M_1$	32.20 ab	34.95
$P_4 M_2$	26.75 cde	29.80
$P_4 M_3$	33.03 a	35.60
$P_4 M_4$	28.80 c	32.80
LSD at 5%	2.821	NS

Any two means not sharing a letter in column differ significantly at $p<0.05$

Table 6. Interactive effect of planting methods and mulching materials on water use efficiency of cotton.

Water use efficiency (μmol(CO_2)/mmol (H_2O)			
Planting methods (P) × Mulches (M)	2004	2005	Mean
$P_1 M_1$	3.76 g	3.29 f	3.53
$P_1 M_2$	2.44 n	2.26 n	2.35
$P_1 M_3$	3.86 f	3.98 c	3.92
$P_1 M_4$	2.88 l	2.74 k	2.81
$P_2 M_1$	2.93 k	2.78 j	2.86
P_2M_2	2.11 o	2.13 o	2.12
P_2M_3	3.17 j	3.39 e	3.28
$P_2 M_4$	2.46 n	2.45 l	2.46
$P_3 M_1$	4.06 e	3.36 e	3.71
$P_3 M_2$	2.75 m	2.43 m	2.59
$P_3 M_3$	4.37 c	4.18 b	4.28
$P_3 M_4$	3.23 i	3.08 h	3.16
$P_4 M_1$	4.77 b	3.84 d	4.31
$P_4 M_2$	3.56 h	3.05 i	3.31
$P_4 M_3$	5.04 a	4.79 a	4.92
$P_4 M_4$	4.27 d	3.18 g	3.73
LSD at 5%	3.118	2.554	

Any two means not sharing a letter in column differ significantly at $p<0.05$

Water use efficiency in crop production is essentially an important concern when resources of irrigation water are limited or moving back and where rainfall is also a limiting factor. In addition, the recent energy crises have made it crucial for irrigated producers to manage inputs to make best use of their water resources. Apart from the situation, it's crucial that growers get the most out of every millimeter of available water, whether that water is received through irrigation, rainfall or both.

Keeping in view the data presented in the afore mentioned tables it may be concluded that the highest water use efficiency was achieved when cotton variety CIM-499 was planted on bed and furrows and mulched with plastic sheet/film. The crop achieved a maximum benefit from the water available in bed and furrow method of planting indicating efficient in irrigation water utilization where as the plastic sheet mulch conserved sufficient moisture for dry matter production as well as avoiding the moisture exploitation by weeds. While 105cm spaced double row planting with paddy straw mulch remained statistically at the lowest position in water use efficiency for both the years (2004 and 2005). The findings are in line with Papamichail *et al.*, (2002) who reported that mulches are among the desired practices for weed suppression and soil improvement. Raman *et al*., (2004 investigated the effect of mulching on the weed control and found that the sugarcane trash mulch reduced the weed number to 20 weeds m^{-2} and weed biomass to 15.19 g m^{-2} and weed control efficiency 91%. These findings are also in consonance with that of Hood (2002) while McAlavy (2004) and Bhattarai (2005) reported that crop water use efficiency can be enhanced by sprinkler or drip irrigation systems. Ghadage *et al*., (2005) reported the highest values for water-use efficiency in paired row planting, alternate furrow irrigation and plastic film mulch. Shaozhong *et al.*, 2002 found that controlled soil water content could improve grain yield, WUE and harvest index in wheat. Buttar *et al.*, (2007) reported 54% increase in water expense efficiency (WEE). Other researchers like Liu-Kang & Hsiao (2004) and Dagdelen *et al.*, (2006) reported that with proper irrigation management/scheduling water use efficiency can be increased.

Total water applied: Data regarding total water applied indicated that different planting methods varied significantly in their water use throughout the crop season regardless of variety. Maximum water (630.0 mm) was used by 70cm spaced single row planting followed by 105cm spaced double/paired row planting with 622.3mm of water during 2004. The minimum quantity of water 468.6 mm was used in bed and furrow method of planting (Table 4). The same trend was observed during the year 2005. The results are partially supported by the findings of Dagdelen *et al*. (2006) who found that under five varying irrigation regimes, the average seasonal water use values ranged from 257 to 867 mm in cotton treatment. Water deficit significantly affected yields of crop.

Table 7. Interactive effect of genotypes × planting methods × mulches on water use efficiency [μ mol (CO_2)/m mol (H_2O)] of two cotton cultivars.

Interactions	2004	2005	Mean
(V1xP1xM1)	3.46 lm	3.12 k	3.29
(V1xP1xM2)	2.34 v	2.25 s	2.30
(V1xP1XM3)	3.48 l	3.59 f	3.54
(V1xP1xM4)	2.68 s	2.92 m	2.80
(V1xP2xM1)	2.67 s	2.72 o	2.70
(V1xP2xM2)	2.16 w	1.87 t	2.02
(V1xP2xM3)	2.91 r	3.37 h	3.14
(V1xP2xM4)	2.39 u	2.40 r	2.40
(V1xP3xM1)	3.89 j	3.32 i	3.61
(V1xP3xM2)	2.51 t	2.27 s	2.39
(V1xP3xM3)	4.31 f	4.11 e	4.21
(V1xP3xM4)	2.92 r	2.91 m	2.92
(V1xP4xM1)	4.58 d	3.24 j	3.91
(V1xP4xM2)	3.24 n	3.15 k	3.20
(V1xP4xM3)	4.89 c	4.45 b	4.67
(V1xP4xM4)	4.12 h	3.06 l	3.59
(V2xP1xM1)	4.05 i	3.46 g	3.76
(V2xP1xM2)	2.54 t	2.27 s	2.41
(V2xP1xM3)	4.23 g	4.38 c	4.31
(V2xP1xM4)	3.08 p	2.57 p	2.83
(V2xP2xM1)	3.19 o	2.86 n	3.03
(V2xP2xM2)	2.06 x	2.40 r	2.23
(V2xP2xM3)	3.44 m	3.40 h	3.42
(V2xP2xM4)	2.52 t	2.51 q	2.52
(V2xP3xM1)	4.23 g	3.41 h	3.82
(V2xP3xM2)	2.99 q	2.58 p	2.79
(V2xP3xM3)	4.44 e	4.24 d	4.34
(V2xP3xM4)	3.54k	3.26j	3.40
(V2xP4xM1)	4.95 b	4.43 b	4.69
(V2xP4xM2)	3.87 j	2.94 m	3.41
(V2xP4xM3)	5.20 a	5.12 a	5.16
(V2xP4xM4)	4.41 e	3.29 i	3.85
LSD at 5%	4.410	3.612	

Any two means not sharing a letter in common differ significantly at $p<0.05$

Quantity of water saved: The data regarding water saving in case of different planting methods in comparison with flood irrigation or flat planting is presented in Table 4. A perusal of the data indicated that during the year 2004, maximum water saving (25.62%) was recorded for 140 cm spaced furrow beds, while 15.0% water saving for 70cm spaced ridge planting method. The lowest quantity of irrigation water was saved (1.22%) in 105 cm spaced double/paired row planting. Similar trend was observed during the year 2005. These results are in line with the findings of previous researchers like Anon., (2001) and De Vries (2000) who reported 30, 75 and 19.8% (average water saving per irrigation turn) water saving in bed-and-furrow compared to line sowing on flat field. Furthermore, lesser (quantity) irrigations prevent over-irrigation and shorten the time per irrigation and enable farmers to irrigate more fields within their irrigation turn (De Vries, 2000). The results also get support from the findings of Saeed & Ahmad (2009) who reported that mulching the soil prevents water loss from soil and facilitate mineral uptake to the plant. Organic mulches helped to maintain moisture content longer than bare soil.

Net income: Net income is the final economic criterion for evaluating the profitability and feasibility of a particular planting technique of cotton crop. Economic analysis for both the years 2004 and 2005 showed net income of two cotton genotypes under different planting methods in combination with mulching practices (Table 8). Among cotton genotypes, higher net income of Rs.23289.6 and 42483.8 ha^{-1} was recorded in case of CIM-499 as compared to Rs.20326.7 and 37777.4 ha^{-1} for CIM-473 during 2004 and 2005, respectively. The highest net income of Rs.27224.2 and 50927.7 ha^{-1} was recorded in bed and furrow planting method followed significantly by Rs.23110.1and 41814.8 ha^{-1} in ridge planting method during 2004 and 2005, respectively. Cotton planted by 105cm/30cm spaced double row, registered the lowest net income of 16470.2 and 29701.0 ha^{-1} during 2004 and 2005, respectively.

As regards mulching techniques, the highest net income of Rs.27382.2 and 47244.5 ha^{-1} was received from plastic sheet mulched cotton crop followed by Rs.25351.0 and 46040.5 ha^{-1} of cultural mulch during 2004 and 2005, respectively. The lowest values Rs.14908.6 and 30232.8 ha^{-1} of net income were obtained in straw mulch in both the years. Thus it is concluded that bed and furrow and ridge planting method not only save irrigation water but also enhance productivity and net income through conducive environments. The mulching practices not only conserve soil moisture, but restrict weed growth as well, thus helping in the enhancement of ultimate net income of the crop.

The maximum net income Rs. 33129.25 ha^{-1} was obtained when crop was planted by bed and furrow planting method and plastic sheet mulch was applied followed by bed and furrow planting method with cultural mulched crop (Rs. 30158.63 ha^{-1}) during the year 2004. Similar trend was observed during the year 2005. On the basis of average of two years, the maximum net income (Rs. 41554.63 ha^{-1}) was obtained when crop was planted by bed and furrow planting method and plastic sheet mulch was applied followed by bed and furrow planting method with cultural mulched crop (Rs. 39386.32 ha^{-1}). The lowest net income (Rs.11576.25 ha^{-1}) was found in case of 105cm spaced double row planting and straw mulch when averaged across the years (Table 9). The results of study get support from the findings of Ghadage *et al.*, (2005) who reported that the highest net returns and cost : benefit ratio were recorded by plastic film mulch, which was closely followed by sugarcane trash (10 tonnes ha^{-1}) as organic mulch.)

Table 8. Net income and cost benefit ratio as affected by cotton genotypes, planting methods and mulching material.

Genotypes (V)	Total expenditure (Rs. ha^{-1})		Gross income (Rs.ha^{-1})		Net income (Rs. ha^{-1})		BCR	
	2004	2005	2004	2005	2004	2005	2004	2005
Planting methods (P)								
V_1 = CIM 473	42144.5	42144.5	62471.2	79201.4	20326.7	37777.4	1.48	1.90
V_2 = CIM 499	42144.5	42144.5	65434.1	84628.3	23289.6	42483.8	1.55	2.01
P_1 = 70cm spaced single row	41919.5	41919.5	62744.9	79998.3	20825.4	38078.8	1.50	1.91
P_2 = 105cm spaced double row	41919.5	41919.5	58389.7	79021.7	16470.2	29701.0	1.39	1.71
P_3 = 70cm spaced ridges	42144.5	42369.5	66478.6	84184.3	23110.1	41814.8	1.54	1.99
P_4 = 140cm spaced furrow beds	42369.5	42369.5	69593.7	94892.0	27224.2	50927.7	1.64	2.20
Mulching materials (M)								
M_1 = Cultural mulch	41512.0	41512.0	66863.0	87552.5	25351.0	46040.5	1.61	2.11
M_2 = Straw mulch	41712.0	41712.0	56620.6	71944.8	14908.6	30232.8	1.36	1.72
M_3 = Sheet mulch	42912.0	42912.0	70294.2	90156.5	27382.2	47244.5	1.64	2.10
M_4 = Chemical mulch	42442.0	42442.0	62625.8	79446.5	19590.8	37968.5	1.46	1.87

Table 9. Interactive effect of planting methods and mulching materials on net income and cost benefit ratio and water use efficiency of cotton.

Interactions	Net income (Rs.)			Cost benefit ratio		
	2004	2005	Mean	2004	2005	Mean
$P_1 M_1$	25521	38545	32033	1:1.62	1:1.80	1:1.71
$P_1 M_2$	12394	20391	16393	1:1.30	1:1.42	1:1.36
$P_1 M_3$	26873	39351	33112	1:1.63	1:1.80	1:1.72
$P_1 M_4$	18509	26932	22721	1:1.44	1:1.55	1:1.50
$P_2 M_1$	19694	28661	24177	1:1.48	1:1.60	1:1.54
P_2M_2	10406	12747	11576	1:1.25	1:1.26	1:1.26
P_2M_3	21161	30251	25706	1:1.50	1:1.61	1:1.56
$P_2 M_4$	14647	20044	17346	1:1.35	1:1.41	1:1.38
$P_3 M_1$	26042	41446	33744	1:1.62	1:1.86	1:1.74
$P_3 M_2$	14511	25420	19966	1:1.35	1:1.52	1:1.44
$P_3 M_3$	28342	42700	35521	1:1.66	1:1.86	1:1.76
$P_3 M_4$	21967	30869	26418	1:1.51	1:1.62	1:1.57
$P_4 M_1$	30159	48614	39386	1:1.72	1:2.00	1:1.86
$P_4 M_2$	22351	35668	29009	1:1.53	1:1.73	1:1.63
$P_4 M_3$	33129	49980	41555	1:1.77	1:2.00	1:1.89
$P_4 M_4$	23262	42629	32946	1:1.55	1:1.86	1:1.71

Cost benefit ratio: Economic analysis across all the planting methods of cotton crop and mulching practices indicated that the highest benefit cost ratio (1:1.77 and 1:2.00) was recorded in case of crop planted by bed and furrow planting method and mulched by plastic sheet during 2004 and 2005, respectively (Table 9). It was followed by bed and furrow planting method with cultural mulched crop with 1:1.72 and 1:2.00 during 2004 and 2005, respectively. Similar trend was observed when averaged across the years. The lowest cost benefit ratio of 1:1.26 was found in case of 105cm spaced double row planting and mulched with rice straw when averaged across the years (Table 9). The results of study get support from the findings of Ghadage *et al*., (2005) who reported that the highest net returns and cost : benefit ratio were recorded by plastic film mulch, which was closely followed by sugarcane trash (10 tonnes ha^{-1}) as organic mulch.

Conclusion

It is concluded that both varieties CIM-473 and CIM-499 performed well but response of cotton variety CIM-499 to the different planting methods along with different mulching techniques was comparatively better. The study also revealed that cotton crop could be grown using bed and furrow planting method mulched with plastic sheet/film for sustainable cotton production and water conservation.

References

Abdel-Al, M.H. 1998. Effect of foliar methanol applications on Egyptian cotton plants. *Egyptian J. Agric. Res.*, 76: 1183-1195.

Akhtar, M., M.S. Cheema and L. Ali. 2003. Effect of planting methods on the yield parameters of four cotton varieties. *J. Anim. P1. Sci.*, 13: 87-90.

Anonymous. 2001. Comparison of cotton crop sowing on flat soil vs bed and furrow. *Annual Progress Report*, 2000-2001, Central Cotton Research Institute, Multan, Pakistan.

Anonymous. 2006. Adaptive Research Recommendations. Agri. Deptt., Govt. of the Punjab, Lahore, Pakistan.

Badaruddin, M., M.P. Reynolds and O.A.A. Ageeb. 1999. Water management in warm environments: effect of organic and inorganic fertilizers, irrigation frequency and mulching. *Agron. J.*, 91: 975-983.

Barnes, C.E. and W.E. Houghton. 1994. Effect of methanol applications on Acala cotton in New Mexico. Proceedings of Beltwide Cotton Conferences, January 5-8, San-Diego, California, USA: 1343-1344.

Basal, H., C.W. Smith, P.S. Thaxton and J.K. Hemphill. 2005. Seedling drought tolerance in upland cotton. *Crop Sci.,* 45: 766-771.

Bhattarai, S.P. 2005. *The physiology of water use efficiency of crops subjected to subsurface drip irrigation, oxygation and salinity in a heavy clay soil*. A Ph.D. Thesis, School of Bio. Env. Sci., Faculty of Arts, Health & Sci., Central Queensland Uni. Rockhampton, QLD 4702, Australia.

Buttar, G.S., M.S. Aujla, H.S. Thind, C.J. Singh and K.S. Saini. 2007. Effect of timing of first and last irrigation on the yield and water use efficiency in cotton. *Agric. Water Manage.,* 89: 236-242.

Chaudhari, C.S., W.S. Pawar, S.N. Mendhe, R.R. Nikam and A.S. Ingole. 2001. Effect of land configuration and nutrient management on yield of rainfed cotton. *J. Soils Crops,* 11: 125-127.

Dagdelen, N., E. Ylmaz, F. Sezgin and T. Gurbuz. 2006. Water-yield relation and water use efficiency of cotton (*Gossypium hirsutum* L.) and second crop corn (*Zea mays* L.) in western Turkey. *Agricultural Water Manage*., 82: 63-85.

De Vries, T.T. 2000. Technical and socio-economic factors influencing the performance of bed-and-furrow irrigation method. In: Report No. R-103: Managing irrigation for environmentally sustainable agriculture in Pakistan. International Water Management Institute, Lahore, Pakistan. pp. 1-28.

Gerik, T.J., K.L. Faver, P.M. Thaxton and K.M. El-Zik. 1996. Late season water stress in cotton. I. Plant growth, water use and yield. *Crop Sci.,* 36: 914–921.

Ghadage, H.L., V.S. Pawar and C.B. Gaikwad. 2005. Influence of planting patterns, irrigation techniques and mulches on growth, yield, water use and economics of cotton (*Gossypium hirsutum*) under irrigated conditions of Western Maharashtra. *Ind. J. Agron.,* 50: 159-161.

Gul, B., K.B. Marwat, G. Hassan, A. Khan, S. Hashim and I.A. Khan. 2009. Impact of tillage, plant population and mulches on biological yield of maize. *Pak. J. Bot*., 41(5): 2243-2249.

Hood, S. 2002. Real water use efficiency and the opportunity. Proceedings of 11th Australian Cotton Conference, Brisbane, Queensland, Australia. pp. 285-295.

Hunt, R. 1978. Plant growth analysis. Edward Arnold, U.K. pp. 26-38 Jackson, B.S. and T.J. Gerik. 1990. Boll shedding and boll load in nitrogen stressed cotton. *Agron. J.,* 82: 483-488.

Javed, T. 1996. Studies on the planting geometry of cotton facilitating intercropping of a few kharif intercrops. M.Sc. Thesis, Department of Agron., Univ. of Agri. Faisalabad.

Keith, E., C. Johnny and B. Mike. 1994. Drought management for cotton production. Electronic publication number DRO-17, December, 1994. North Carolina cooperative extension service, North Carolina State University, Raleigh, North Carolina.

Khalid, H.K., M.A. Rana and M. Arshad. 1999. Alternate furrow irrigation for enhancing water use efficiency in cotton. *Pak. J. Agri. Sci.,* 36(3-4): 175-177 [Cab Absts., 1998-2000].

Khan, N.U., K.B. Marwat, G. Hassan, Farhatullah, S. Batool, K. Makhdoom, W. Ahmad and H.U. Khan. 2010. Genetic variation and heritability for cotton seed, fiber and oil traits in *Gossypium hirsutum* L. *Pak. J. Bot*., 42: 615-625.

Khan, S.R.A. 2001. Water requirements of crops. Crop Management in Pakistan with focus on soil and water. Directorate of Agricultural Information, Punjab Lahore (Pakistan).

Kumar, B., D.M. Pandey, C.L. Goswami and S. Jain. 2001. Effect of growth regulators on photosynthesis, transpiration and related parameters in water stressed cotton. *Biol. Plant.,* 44: 475-478.

Liu-Kang, Xu and T.C. Hsiao. 2004. Predicted versus measured photosynthetic water use efficiency of crop stands under dynamically changing field environment. *J. Exp. Bot.,* 55: 2395-2411.

Madiwalar, S.L. and A.S. Prabhakar. 1998. Effect of method of sowing and weed management treatments on growth and yield of hybrid cotton in hillzone. Karnataka. *J. Agric. Sci.,*11: 8-11.

Makhdum, M. I. 2003. *Response of some cotton cultivars to sulphate of potash (SOP) and muriate of potash (MOP)*. Ph.D. Thesis. Department of Chemistry, Faculty of Science and Agriculture, Bahauddin Zakariya University, Multan, Pakistan

Makhdum, M.I., M.NA. Malik, Shabab-ud-din, F. Ahmad and F.I. Chaudhry 2002. Physiological response of cotton to methanol foliar application *J. Res. (Sci.*), Bahauddin Zakariya University, Multan, Pakistan. 13: pp. 37-43

Mauney, J.R. 1986. Vegetative growth and development of fruiting sites. *In:* Cotton Physiology. (Eds.): J.R. Mauney and J. McD Stewart. *The Cotton Foundation,* Memphis, TN. USA. pp. 11-28.

McAlavy, T.W. 2004. Researchers Investigate cotton irrigation strategies. Tim W. McAlavy (806) 746-6101, t-mcalavy @tamu.edu. Agricultural Communications Taxas A & M University System 2112 TAMUS.

Mullins, G. L. and C. H. Burmester. 1990. Dry matter, nitrogen, phosphorus and potassium accumulation by four cotton varieties. *Agron. J.*, 82: 729-736.

Nepomuceno, L., D.M. Oosterhuis and J. McD. Stewart. 1998. Physiological responses of cotton leaves and roots to water deficit induced by polyethylene glycol. *Environ. Exp. Bot.*, 40: 29-41.

Norton, E.R. and H.J.C. Silvertooth. 2001. Evaluation of drip vs. furrow irrigated cotton production system. Arizona Cotton Report. The Uni. of Arizona, College of Agri. and Life Sciences, USA.

Pace, P.F., H.T. Cralle, S.H.M. El-Halawany, J.T. Cothren and S.A. Senseman. 1999. Drought-induced changes in shoot and root growth of young cotton plants. *J. Cotton Sci.,* 3: 183–187.

Papamichail, D., I. Eleftherohorinos, R.F. Williams and F. Gravanis. 2002. Critical periods of weed competition in cotton in Greece. *Phytoparasitica,* 30: 105–111.

Raman, R., G. Kuppuswamy and R. Krishnamoorthy. 2004. Effect of mulching on the growth and yield of cotton. *J. Ecobiol.,* 16: 275-278

Randall, P.J., Q. Wang, P.J. Hocking and A. Pinkerton. 1997. Critical values for sulphur in young plants of oilseed rape (*Brassica napus* L.) determined with reference to dry weight, leaf area and specific leaf weight. *Plant Soil,* 78: 97-98.

Robert, J.L., R.L. Baumhardt, S.K. Hicks and J.L. Heilman. 2000. Soil and plant water evaporation from strip-tilled cotton: Measurement and Simulation. *Agron. J.,* 86: 987-994.

Saeed, M. 1994. Crop water requirements and irrigation systems. In: Crop Production. (Eds.): Shafi Nazir. National Book Foundation, Islamabad. pp. 49-81.

Saeed. R. and R. Ahmad. 2009. Vegetative growth and yield of tomato as affected by the application of organic mulch and gypsum under saline rhizosphere. *Pak. J. Bot*., 41(6): 3093-3105.

Sampathkumar, T., S. Krishnasamy, K. Ramesh and K. Shanmugasundaram. 2006. Effect of drip and surface irrigation methods with rice straw mulch on productivity and water use efficiency of summer cotton. *Crop Res. Hisar*, 32: 141-144.

Shaozhong, Kang., Lu Zhang, Yinli Liang and Huanijie Cai. 2002. Effects of limited irrigation on yield and water use efficiency of winter wheat on the loess Ploteau of China. ACIAR Monograph No. 84. pp. 105-116.

Steel, R.G.D., J.H. Torrie and D.A. Dickey. 1997. *Principles and procedures of statistics*. McGraw Hill Book Co., Inc. New York.

Stiller, W. N., J.J. Read, G.A. Constable and P.E. Reid. 2005. Selection for water use efficiency traits in a cotton breeding program: Cultivar Differences Published online May 6, 2005.

Subrahmaniyan, K. and P. Kalaiselvan. 2005. Flowering behaviour and reproductive growth of polyethylene film-mulched groundnut (*Arachis hypogaea*) intercropped with cotton (*Gossypium hirsutum*) under irrigated situation. *Ind. J. Agron.*, 50: 126-128.

Teama, E.A., E.E. Mahdy and K.A.A.El. Rahman. 2000. Effect of mechanical planting methods and seeding rates on yield, earliness and technological properties of some Egyptian cotton varieties. *Assiut J. Agric. Sci*., 31: 169-186.

Wells, R. and W.R. Meredith Jr. 1984. Comparative growth of obsolete and modern cotton cultivars: II. Reproductive dry matter partitioning. *Crop Sci*., 24: 863-868.

Wiese, A.F., W.L. Harman and C. Regier. 1994. Economic evaluation of conservation tillage systems for dry level and irrigated cotton (*Gossypium hirsutum* L.) in the Southern great plains. *Weed Sci.,* 42: 316-321.

ZongBin, M., Li-LingLi, Fang-WeiPing, Xie-DeYi and Yang-TieGang. 2004. Effect of wheat straw mulching on soil temperature, moisture and growth and development of summer cotton. *J. Henan Agric. University*, 38: 379-383.

(Received for publication 15 October 2010)