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BOTANY

Cotton productivity enhanced through transplanting and early sowing

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ABSTRACT. Due to high temperatures in arid regions, cotton crop emergence and early establishment of seedlings are adversely affected. Field studies were undertaken to quantify the effects of transplantation of cotton (*Gossypium hirsutum* L.) seedlings during the early part of the growing season (March) and crop season (May) for potential realization of cotton productivity under the harsh weather of the southern part of Punjab province, Pakistan. Treatments, consisting of (a) two planting dates (March and May), and (b) two sowing methods (transplanting of seedlings and direct seeding), were arranged in a randomized complete-block design with four replications. Results showed that transplanting seedlings improved the productivity of cotton by 14.2% over direct seeding. Productivity was also increased substantially (34.8%) by planting during March over May sowing. The practice of planting cotton by transplanting seedlings and early sowing could be successfully adapted in areas where high temperatures coincide with the May planting and peak blooming periods in different cotton growing areas.

Keywords: heat stress; irrigated arid environment; planting techniques; planting time.

Aumento da produtividade do algodão por meio de transplante de mudas e semeadura precoce

RESUMO. Altas temperaturas, em torno de 48ºC, prevalecem durante os meses de maio na parte do sul da província de Punjab, no Paquistão. A esta temperatura a emergência da colheita de algodão e o estabelecimento precoce da plântula são adversamente afetados. Estudos de campo foram realizados para quantificar os efeitos do transplante de mudas de algodão (*Gossypium hirsutum* L.) durante a primeira parte da estação de crescimento (março) e da safra (maio) para a realização potencial da produtividade do algodão sob condições adversas da parte sul do Punjab Província-Paquistão. Os tratamentos, consistindo em (a) duas datas de plantio (março e maio), e (b) dois métodos de semeadura (transplante de mudas e semeadura direta), foram dispostos em delineamento em blocos ao acaso com quatro repetições. Os resultados mostraram que o transplante de mudas melhorou a produtividade do algodão em 14,2% em relação à semeadura direta. A produtividade também aumentou substancialmente (34,8%) com o plantio em março sobre a semeadura de maio. A prática de plantio de algodão por transplante de mudas e sua semeadura precoce poderia ser adaptada com sucesso, onde a alta temperatura coincide com o tempo de plantio durante o mês de maio e períodos de florescimento máximo em diferentes áreas de cultivo de algodão.

Palavras-chave: estresse por calor; ambiente árido irrigado; técnicas de plantio; tempo de plantio.

Introduction

Cotton (*Gossypium hirsutum* L.) is an important crop world-wide (Buttar et al., 2013; Jalota et al., 2008; Mayee, Monga, Dhillon, Nehra, & Pundhir, 2008; Ahmad et al., 2017). In the world, Pakistan ranks as the fourth-largest cotton producer in terms of area and production after China, India and USA, and third-largest consumer after China and India. Pakistan has been trying to maintain its position among cotton producers and consumers in the world (Shafiq & Rehman, 2000; Wajid et al., 2010; Ali et al., 2013a; 2013b; Ahmad & Raza, 2014; Ahmad et al., 2014; 2015).

The prevalence of high temperatures (45-48ºC) during the cotton-growing season, especially in the early and mid-season, limits potential yield of the cotton crop in this part of the world (Ali, Afzal, Ahmad, & Muhammad, 2009; Usman et al., 2009; Ali et al., 2010; 2013a; 2013b; Ahmad et al., 2014; Ahmad & Raza, 2014;

Amin et al., 2017a; 2017b). It is commonly understood that flowers appearing during July and August cannot produce good quality lint due to the poor opening of harvestable bolls under the prevalence of high temperatures during this growth period (Dong, Zhang, Tang, Li, & Li, 2005a; Dong, Li, Tang, Li, & Zhang, 2005b; Ali et al., 2010; Tariq et al., 2017). Thereby, early planting during March may reduce the chance of adverse effects of early and mid-season high temperatures (Pettigrew, 2002; Khan, Khaliq, & Ahmad, 2004; Ali et al., 2009; Usman et al., 2009; 2010; Wajid et al., 2010; Ali, Hameed, Ahmad, Shahzad, & Sarwar, 2014a; Ali et al., 2014b). The planting of cotton during high temperatures increases the risk of exposing the cotton seedlings to heat stress, which ultimately results in poor plant population (Ali et al., 2010; 2011; Tariq et al., 2017; Ahmad et al., 2017). In the past five years, cotton growers have shifted to the early planting of cotton to avoid the risk of heat stress on the emergence of seedlings during May and maintain optimum plant population. Of the other potential options, transplanting cotton seedlings offers the best opportunity for the proper establishment of cotton seedlings under high temperatures. In this system, cotton seedlings are raised in a greenhouse during the early season, then transplanted to open fields in March (Dong, Li, Tang, & Zhang, 2004; Dong et al., 2005a; 2005b; Ali et al., 2010). Transplanted cotton has been found to be profitable because it maintains optimum plant population and a greater number of bolls per unit area. Similarly, advantages of transplanted cotton relative to seed cotton and lint yield have been found in other cotton-growing countries (El-Sahrigi, Kamel, & El- Khatib, 2001; Karve, 2003; Dong, Li, Tang, Li, & Zhang, 2007). Very little research has been conducted and reported regarding enhancing productivity by transplanting during the early growing season to avoid high temperatures at the time of planting and reproductive development. Therefore, field studies were undertaken to quantify the effects of early sowing and transplanting of seedlings on cotton productivity in comparison to the traditional time and method of sowing.

Material and methods

The field experiments were conducted at Cotton Research Station, Multan (71.43 E, 30.2 N, 122-meter altitude) during the growing seasons 2011 and 2012. The climate is very hot during summer and very cold during winter, and the annual rainfall is below 100 mm. The maximum temperature varied from 16.6 to 48.8°C, and minimum temperature ranged from 7.5 to 32°C (Figure 1). The nursery of cotton seedlings (cv. MNH-886) was raised in polyethylene pots (Figure 2). The pots were filled with 0.5 kg of sandy clay loam soil, and 2-3 seeds were dibbled. The nursery for the early sown crop (March) was kept in the greenhouse during both years, and the nursery pots were kept in open space for the seasonal sown crop (May). Sowing of the nursery was done on 15th February for the early sown crop during both years and on 15th April for the seasonal crop. Nursery seedlings were irrigated with a shower until seedlings gained a height of 10-12 cm. The nursery of cotton seedlings was transplanted in the field on raised beds on 1st March for early sowing and 1st May for seasonal sowing. Small holes were dug manually on the edge of the furrows at 30 cm apart from plant to plant, then polyethylene pots were placed in the holes after puncturing their bottom. The direct sowing of the crop was also done on the same day. The treatments consisted of two times of planting, i.e., early sowing (March) and seasonal sowing (May), and two methods of sowing (transplanting of seedlings and direct seeding) and were arranged in a randomized complete block design with four replications. The standard agronomic practices were carried out during the season. The soil was alluvial, calcareous and alkaline in reaction, free from any physical impediments and well drained. The fertility status of the soil was medium and deficient in nitrogen and phosphorus. The basal dose of N, P and K was applied at the rate of 120 kg N, 50 kg P_2O_5 and 30 kg K_2O ha^{-1}. The entire quantity of phosphorus, potassium, and one-third of nitrogen was applied at planting, and the remaining nitrogen was applied in equal quantity at first flower and peak flowering stage. A total of eight irrigations were applied to the cotton crop. The amount of water per irrigation was 75 mm. The crop was protected against insect pests at the economic threshold level (ETL) and was harvested during October. At the time of harvest, seed cotton was picked manually, and data were collected on the area bases. Data on yield components, i.e., number of bolls per plant, boll weight and plant height, were also recorded by randomly harvesting cotton plants from one square meter area from three places in the experimental plots. Data were analyzed statistically according to the methods of Steel, Torrie, and Dickey (1997).

Results and discussion

Data for main stem height and number of nodes per plant differed significantly depending on the time of sowing, planting methods and their interactions (Table 1 and 2). The early-sown crop (during March) attained higher plant height compared to the seasonally sown crop (during May). Moreover, the transplanted crop attained a significantly higher plant height and number of nodes on the main stem compared to the direct seeding crop. The crop planted in March through transplantation of seedlings attained the highest plant height and number of nodes compared to direct seeding during March. The transplanted crop attained 1.7% higher plant height compared to direct seeding. Additionally, the March planting attained 6% higher plant height compared to seasonal sowing. The substantial increase in plant height in the transplanted crop is due to earlier attainment of higher vegetative growth under favorable weather conditions compared to passing through its establishment stage under harsh weather conditions.

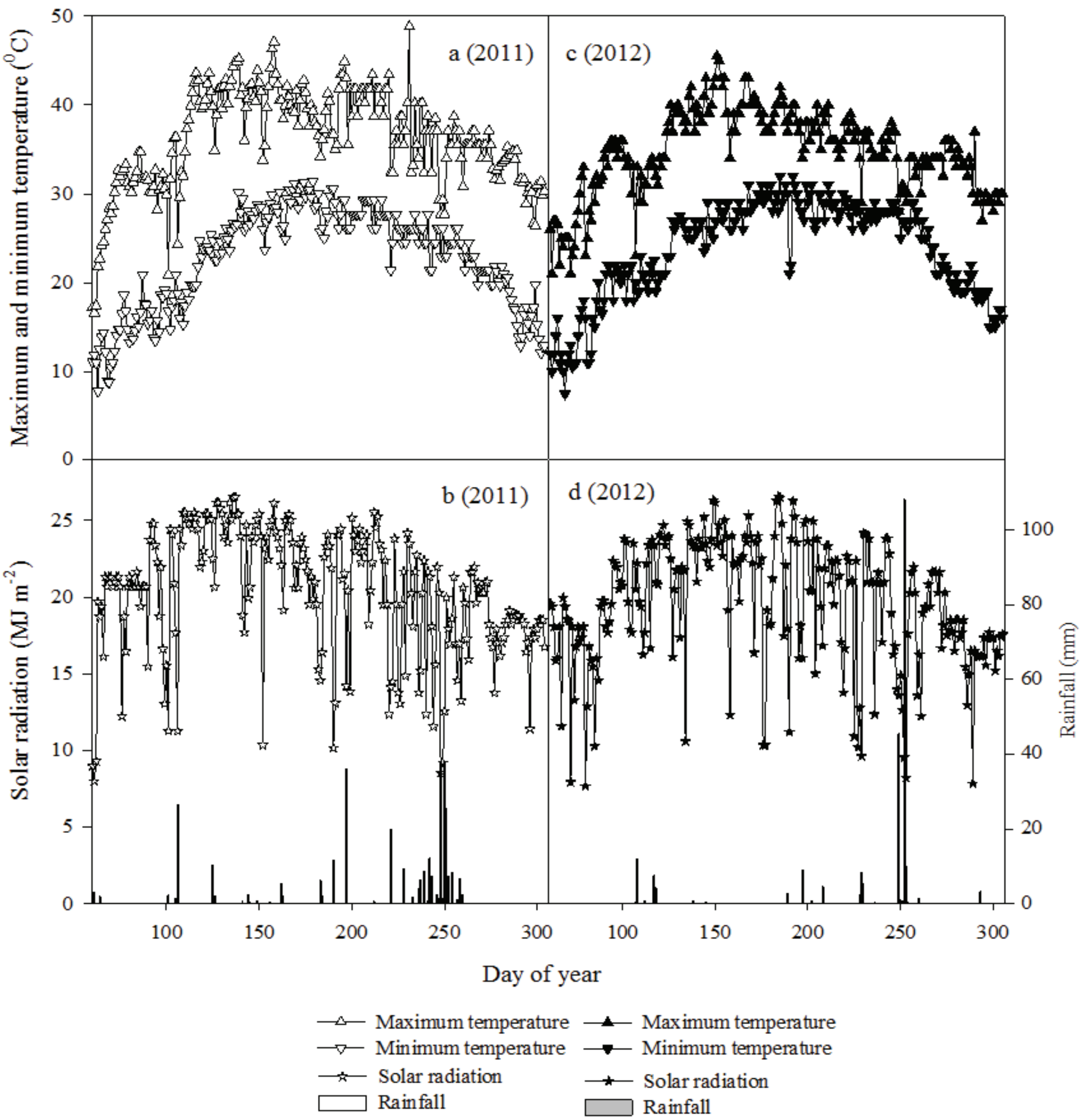

Figure 1. Daily maximum and minimum temperatures (a, c), solar radiation and rainfall (b, d) of the experimental location during 2011 (unfilled symbols) and 2012 (filled symbols) at Multan, Pakistan.

Figure 2. The nursery of cotton seedlings in polyethylene bags.

It is well evidenced that vigorous growth during the establishment period and maintenance of proper plant density results in higher productivity than that of thinly populated and retarded growth during harsh temperature.

The components of seed cotton yield were also significantly affected by differential treatments of planting time and methods and their interactions. Averaged across two seasons, the crop sown in March retained 39.1 bolls compared to 31.0 bolls per plant in May sown crop, i.e., 26% more bolls were gathered from March planting over the May planted crop. Furthermore, the transplanted crop produced 17.4% higher number of bolls compared to direct seeding. Similarly, the crop planted in March through transplanting retained the maximum number of bolls compared to other interactions. The crop planted during March produced heavier bolls by 5.8% compared to the May sown crop. Similarly, the transplanted crop witnessed an edge of 1.6% heavier bolls in comparison with the direct seeding method. There was a strong interaction for production of heavier bolls by planting crop during the month of March by transplanting method. The production of a higher number of bolls per plant and heavier bolls in differential treatments resulted in a higher productivity of cotton. On average, the crops planted in March and May produced 3986 and 2957 kg ha-1 seed cotton yield, respectively. Data show that a 34.8% higher seed cotton yield was achieved by planting the crop during March rather than May. Similarly, a 14.2% higher seed cotton yield was harvested from the transplanted crop in comparison to the crop from direct seeding.

The interaction between March sowing and transplanting of seedlings caused significant differences in producing seed cotton yield in comparison with other interactions under study.

Table 1. Summary of ANOVA of different yield parameters.

Sources of Variation/Parameters	Mean Square					
	Degree of freedom	Plant height	Nodes plant^{-1}	Bolls plant^{-1}	Boll weight (g)	Seedcotton (kg ha^{-1})
Replication (Rep)	3	15.11	14.66	18.27	0.22748	314384.00
Year (Y)	1	9563.45	521.65	19.88	0.04351	4005.13
Error Rep×Y	3	11.62	14.06	2.69	0.06597	745.04
Sowing Time (ST)	1	19.84	4.35	948.52	0.23805	1.000E+07
Y×ST	1	345.84	4.65	12.28	0.01361	171405.00
Error Rep×Y×ST	6	14.02	28.19	7.75	0.02107	3517.96
Sowing Method	1	3911.70	76.26	100.04	0.02761	1051975.00
Y×SM	1	94.53	2.76	0.91	0.00180	1485.12
ST×SM	1	485.16	46.08	23.15	0.04061	1891.13
Y×ST×SM	1	181.45	13.01	2.01	0.00125	50403.10
Error Rep×Y×ST×SM	12	14.05	4.22	12.92	0.06399	9918.29
Total	31					

Table 2. Growth and seed cotton yield as affected by sowing times and methods under irrigated arid environment.

Treatments	Plant height (cm)		Nodes plant^{-1}		Bolls plant^{-1}		Boll weight (g)		Seedcotton (kg ha^{-1})	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Sowing Time										
March sowing [T_1]	162.50	132.8b	44.70	36.00	37.83a	40.33a	3.09a	3.12a	3933a	4039a
May sowing [T_2]	159.50	120.17a	43.50	36.00	32.67b	29.33b	2.87b	2.98b	3041b	2872b
LSD 5%		3.79			2.59	7.55	0.11	0.14	526.64	1137.6
Sowing Method										
Transplanted [M_1]	170.33a	139.33a	45.30a	37.83a	44.17a	42.33a	3.00	3.08	4272a	4144a
Direct seeded [M_2]	151.67b	113.67b	42.83b	34.16b	36.33b	37.33b	2.96	3.02	3703b	3667b
LSD 5%	7.96	7.71	1.96	2.17	3.61	3.46			198.18	256.79
Sowing time × Sowing method										
$T_1 \times M_1$	174.33	141.47a	46.67	39.67a	43.47a	44.00a	3.14	3.20	4156	4374
$T_1 \times M_2$	152.67	103.33c	43.00	32.33c	39.11b	37.92ab	3.04	3.04	3871	3902
$T_2 \times M_1$	166.33	137.00a	44.00	36.00b	32.67c	29.67c	2.87	2.98	3248	3013
$T_2 \times M_2$	150.67	124.00b	42.67	36.00b	30.67c	28.00c	2.88	2.99	2835	2732
LSD 5%		8.50		2.47	4.37	8.16				

Means sharing different letters differ significantly from each other by LSD at p ($\leq$ 0.05).

The transplanted crop planted during March retained a greater number of bolls on the first three positions along sympodia due to favorable weather conditions during the earlier part of their reproductive development. The retention of the bolls near the main stem accumulated greater photosynthates compared to bolls present on the periphery of the sympodia. Averaged across two seasons, the net returns from the transplanted cotton were US$2580 compared to 2238 derived from the direct seeding system. Moreover, planting cotton during the earlier part of the season brought a net return of US$2399 compared to 1712 received from the normal sowing period (Table 3).

The cotton plant has characteristics of indeterminate growth habit because vegetative and reproductive growth occurs simultaneously during the season. The development of buds, flowers, and bolls require differential needs for their development, and thereby are sensitive to external environments (Tariq et al., 2017; Ahmad et al., 2017). The production of greater dry matter of reproductive parts compared to vegetative parts results in higher yields. The development of vigorous growth during the early part of the growth season supports the crop in combating the harsh environments during reproductive growth (Jost & Cothren, 2000; Gormus & Yucel, 2002). In most of the cases, the shifting of cotton planting in early season is restricted due to lower soil temperature (Basavanneppa, Briadar, & Yelamali, 2001; Shastry, Sharma, & Mandloi, 2001; Dong et al., 2003). This limitation can be avoided by raising the planting nursery into a greenhouse-like environment and then planting in the field (Zhang, Li, Wang, & Nan, 2012). This strategy gives the best option for improving the earliness indices, i.e., early flowering, its lengthening period and more importantly, early maturing of bolls (Xiang et al., 2006). Dong et al. (2007) also reported that transplantation of cotton seedlings during the early season aided in extending the period of reproductive development (flowering and bolling), thus improving the reproductive-vegetative ratio during the season. Wang, Isoda, and Wang (2004) reported that the transplanting of cotton could allow the crop to escape early and mid-season weather stress in certain production areas. Pettigrew (2002) advocated that the period of peak flowering could be lengthened by the early shifting of cotton plantings. Ali et al. (2013a; 2013b), Ahmad and Raza (2014) and Ahmad et al. (2014; 2017) have all reported that agronomic practices offer potential options, i.e., change in planting date, plant geometry and plant densities, to increase harvest yield and quality of lint. Pettigrew (2002) reported an increase of 10% improvement in cotton yield from an early-planted crop compared to a normally sown crop. The enhancement in yield was attributed to a higher number of bolls per unit area and production of heavier bolls. Moreover, the retention of bolls on the first three positions along the sympodia contributed greatly towards the production. The early sown crop witnessed a lower abortion rate of fruit and resulted in retaining a greater number of bolls on the plants (Ahmad et al., 2014; Ahmad & Raza, 2014; Ali et al., 2014a; 2014b).

Table 3. Economic analysis for production of cotton under different planting techniques and timings.

Treatments	Output value ($ ha^{-1})		Input value ($ ha^{-1})		Net revenue ($ ha^{-1})	
	2011	2012	2011	2012	2011	2012
Sowing Time						
March sowing [T_1]	2622	2693	247	271	2375	2422
May sowing [T_2]	2027	1915	247	271	1780	1644
LSD 5%	538	492	26	38	474	565
Sowing Method						
Transplanted [M_1]	2848	2829	247	271	2601	2558
Direct seeded [M_2]	2469	2445	216	222	2253	2223
LSD 5%	274	311	24	36	329	299
Sowing time × Sowing method						
$T_1 \times M_1$	2771	2916	247	271	2524	2645
$T_1 \times M_2$	2581	2601	216	222	2365	2379
$T_2 \times M_1$	2165	2009	247	272	1918	1738
$T_2 \times M_2$	1890	1821	216	222	1674	1599
LSD 5%	512	483	27	44	556	483

Means sharing different letters differ significantly from each other by LSD at p ($\leq$ 0.05). Input variable values mainly comprised of polyethylene bags, seed cost and labor charges, while, fertilizer, irrigation and pesticide cost values were same for both systems. The values of net return were converted from PKR to US$.

The results of this study show that cotton transplanted during the early season translated into higher production by 14.2% over direct seeding. The improvement in yield also occurred by transplanting cotton during the early period (March) compared to the normal sowing period (May). The early-season transplanted crop initiated its reproductive development ten days earlier than the direct seeding method (Figure 3). The initiation of early vegetative development, production of a higher number of fruiting bodies and their retention on earlier positions along sympodia made the crop earlier to mature than a normally seeded crop. Similar results have also been reported by Dong et al. (2007) that manipulating cotton planting by transplanting cotton seedlings in the early part of the season avoided the hazards of high temperature during months of May and June and lengthened the reproductive development for higher productivity.

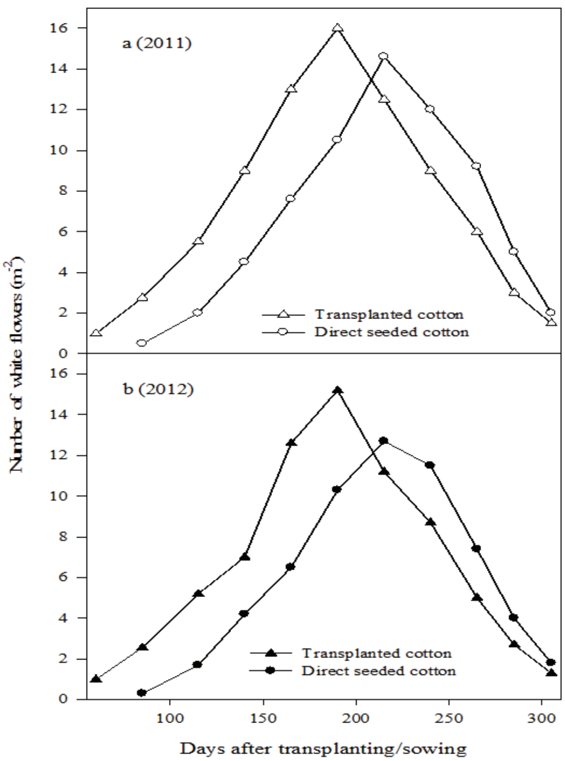

Figure 3. Number of white flowers (m^{-2}) in transplanted and direct seeded cotton during 2011 (un-filled symbols) and 2012 (filled symbols).

Conclusion

Cotton crops are highly susceptible to weather vagaries, and harvesting its potential is a means of maintaining the edge of reproductive development over vegetative growth. The hazards of harsh weather could be avoided by transplanting cotton seedlings during the early part of the season instead of using the conventional planting method. The productivity of cotton crops could be improved by 14% over the direct seeding method by transplanting seedlings. Moreover, this profitability could be further increased substantially (35%) by planting cotton during the month of March compared to May.

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