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ULTRA-NARROW ROW SPACING: A SUSTAINABLE AND ECONOMICAL APPROACH ENSURING PROFITABLE COTTON PRODUCTION

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Cotton (*Gossypium hirsutum* L.) is well-known to be a white gold and cash crop of Pakistan. Recently, improper plant populations and miss-use of nitrogenous fertilizers diminished the growth and yield of the cotton crop. In this scenario, a study was carried out to determine the optimum dose of nitrogen and the best sowing method, using various row spacing, to achieve the maximum cotton yield potential. The experiment was laid out in RCBD (Randomized Complete Block Design) with a factorial arrangement having three replications. Experiment was comprised of two factors i.e. nitrogen (120 and 150 kg ha^{-1}) and row spacing {ultra-narrow (15cm), narrow (30cm) and conventional (75cm)}. Increasing trend of data regarding growth and development (plant population ha^{-1}, plant height, number of nodes $plant^{-1}$, number of squares $plant^{-1}$, number of monopodial and sympodial branches $plant^{-1}$, and number of flowers $plant^{-1}$), yield components (number of open and un-open bolls $plants^{-1}$, average boll weight (g), seed cotton yield (kg ha^{-1}), ginning out-turn (GOT%), quality parameter (staple length, micronaire, fiber strength, fiber fineness, fiber uniformity) and benefit-cost ratio (BCR) of cotton were observed under applied UNR treatment from the crop using standard procedures. Maximum seed cotton yield was obtained by adopting the planting method with 15 cm ultra-narrow-row (UNR) along-with 150 kg ha^{-1} nitrogen application during both the years (2015 and 2016) of the field experiment. The finding of the research is recommended for the farming community to adopt the newly emerged ultra-narrow row's technique at 15 cm row spacing to get the economically profitable seed cotton yield under the recent agro-climatic fluctuation of Southern Punjab, Pakistan.

Keyword: BCR, nitrogen, plant density, seed cotton yield, UNR

INTRODUCTION

Benefits associated with cotton crop production is decremented due to the various drastic aspects including farmers' lack of knowledge, unleveled ridges, miss-use of fertilizer application, non-selective pesticides, un-compatible biological control etc. (Men *et al*., 2003). Inadequate plant density is the most important limiting factor in the cotton production of Pakistan (Khan *et al*., 2007). Cotton is the main source of raw material for the textile industry and foreign exchange earnings for Pakistan. But the sub-optimal plant population per unit area has aggravated the problem of low yield in the region (Hussain *et al*., 2007).

Thus, alternative agronomic management strategies are needed to ameliorate the problem related to the plant population in the cotton field (Nadeem *et al*., 2010). Cotton plant assumed to be a sensitive against sudden fluctuation in agro-climatic conditions, so espousing the seeds in the rows is the most important concerning factor. Cotton plant population directly proportions to row-row and plant-plant spacing, which determined not only crop production but also the quality of fiber (Subhan *et al*., 2001). Usually, the farmers grow cotton with 75 cm row-row distance, which results in the extended growth period and irregular formation of sympodial branches (Rajakumar *et al*., 2010).

Ultra-narrow row spacing is a sustainable agronomic technique to reduce the possible losses of cotton and enhanced the uniformity of plant density in the field condition (Reddy *et al*., 2009). It provides the optimum aeration and plant growth, ultimately leading to enhanced seed cotton yield. Maximum seed cotton yield by maintaining inter-node distance, uniform boll formations, average boll weight and shortening the life cycle under UNR system of planting (Seibert *et al*., 2006). Observations proved that the yield loss, due to the reduced number of sympodial branches, leaves, and flowers per plant in UNR planting system, can be compensated with enhanced plant population. Higher plant populations non-significantly yielded short height plants with implementing the various narrow row spacings in the cotton field (Hamid *et al*., 2016). Cotton plants, grown in the UNR system, showed a diversified response to plant growth regulators. Mepiquat chloride (MQC), a growth retardant, can be used to suppress the excessive plant growth like plant height, length of branches, inter-node distance, and leaf area index etc. (Abbas *et al*., 2010).

Nitrogen (N) plays an important role in seedlings establishment (Sarkar and Malik, 2004; Das *et al*., 2014). Increase in nitrogen use efficiency significantly enhanced plant density. The application of the higher amount of N encouraged the quick growth at early stages which prevented the yield loss. The decrease in N availability adversely affected the seedlings establishment, which leads to a reduction in vegetative and reproductive phases of plant growth (John *et al*., 2006).

Keeping in view the above-mentioned facts, the present study was carried out to check the growth, yield, and quality of cotton in UNR as compared to conventional method along with the application of different nitrogen doses under the agro-climatic condition of Southern Punjab, Pakistan.

MATERIALS AND METHODS

***Experimental sites*:** The research work was conducted during 2015 and 2016 at Agronomic Research Farm, Department of Agronomy Faculty of Agricultural Sciences and Technology Bahauddin Zakariya University, Multan, Pakistan (71.50 °E, 30.26 °N and altitude 123 m). The climate of the Multan region is semi-arid sub-tropical. The soil physio-chemical properties of soil are shown in Table 1. The texture of the experimental soil was silty clay loam. The seed of genotype MNH-886 for the experiment was acquired from Punjab Seed Corporation, Khanewal, Pakistan.

Table 1. Soil analysis of agronomy experimental site of Bahauddin Zakariya University, Multan Pakistan.

Determination	Unit	2015	2016
Soil physical analysis			
Sand	%	23.12	23.298
Silt	%	59.14	59.331
Clay	%	17.11	18.022
Texture		Silty clay loam	
Soil chemical analysis			
Organic matter	%	0.63	0.81
Saturation	%	39.00	39.19
Total Nitrogen	%	0.05	0.96
Available Phosphorus	ppm	5.50	6.42
Available Potassium	ppm	103.00	105.92
EC	dS m^{-1}	3.09	3.79
pH	-	7.90	8.59
Zinc	ppm	0.36	0.36
$CaCO_3$	%	9.00	9.00

***Experimental details*:** The experiment was laid out in RCBD with a factorial arrangement having three replications. The experiment was comprised of two factors. Factor A: Two levels of Nitrogen, N_0 (Control treatment as recommended dose of nitrogen @120 kg ha^{-1}), and N_1 (application of nitrogen @150 kg ha^{-1}). Factor B: various row spacing {UNR (15cm), Narrow (30cm), and Conventional (75cm)}.

***Crop husbandry*:** Cotton seeds were sown during the 1st week of May 2015 and 2016, as per different row spacing treatment, described above. Plant height was maintained up to 90cm by foliar application of mepiquat chloride @ 123.55 ml ha^{-1}twice before anthesis. The net plot size for the experimental unit was 3.75 × 6.10 m^2. Nitrogen was applied as urea in 3 splits; 1st at sowing, 2nd at 1st irrigation and 3rd at peak anthesis stage. Phosphorus (Di-ammonium phosphate) and potash fertilizers (Sulphate of potash) were applied @ 65 and 55 kg ha^{-1} respectively. Irrigated was applied as per crop requirements to avoid moisture stress. Manual hoeing and foot manuring were practiced to control the weeds. Possible integrated pest management (IPM) and Imidacloprid (Confidor 200-SL) were applied for insect-pest control in the cotton field. All other agronomic practices were kept uniform throughout the experiment. The last picking was collected in the last fortnight of October during both years of trial.

***Evaluations and observations*:** Ten plants were randomly selected to evaluate plant height, number of nodes $plant^{-1}$, number of squares $plant^{-1}$, monopodial branches $plant^{-1}$, sympodial branches $plant^{-1}$ and number of flowers $plant^{-1}$. The average boll weight was measured in 20 randomly selected mature bolls and preserved for the measurement of quality traits (staple length, staple micronaire, fiber strength, fiber elongation, fiber fineness, fiber uniformity). The crop was handpicked thrice. First picking was done at approximately 60% boll opening, followed by 2nd and 3rd picking at 20 days interval each. Final yield was expressed as seed cotton yield (kg ha^{-1}) during the years 2015 and 2016.

***Benefit-cost ratio* (*BCR*):** Most suitable planting method for cotton production based on economic analysis was determined. Economic analysis consisted of total expenditure, net income, gross income, and benefit-cost ratio. Total expenditure (cost) included land-rent, seedbed preparation, purchase and treatment of cottonseed, labor, fertilizers, plant protection measures, irrigation charges and picking of crops. Gross income was calculated according to the recent market prices of seed cotton and cotton stalk in Pakistan (1USD= 105.45 PKR). Net income was obtained by subtracting the total expenditure from gross income. Finally, BCR was calculated as the ratio of gross incomes to total expenditures.

***Meteorological data*:** Meteorological data, collected from Agricultural Meteorology Cell, Central Cotton Research Institute, Multan, Pakistan is presented in Figure 1.

***Statistical analysis*:** Data was analyzed by Fisher's analysis of variance method, using MSTAT software. Moreover, Duncan's Multiple Range Test (DMRT) was employed for treatment means at 5% probability of significance (Steel *et al*., 1997).

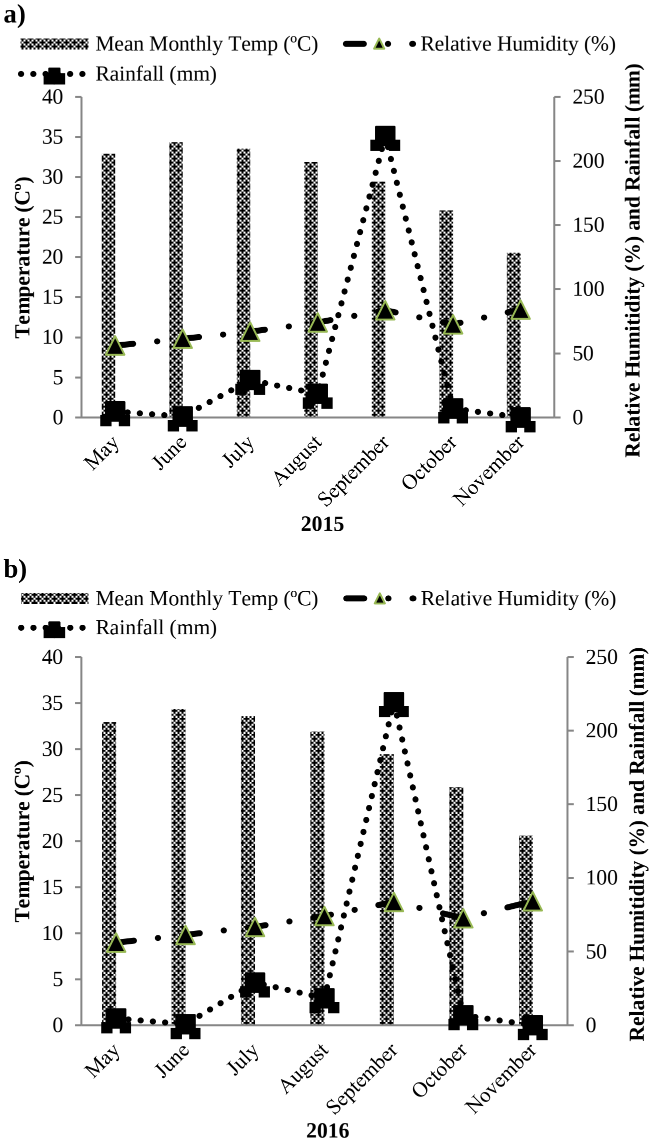

Figure 1. Weather data of Southern Punjab, Multan during cotton crop growth.

Source: Agricultural Meteorology Cell, Central Cotton Research Institute, Multan, Pakistan.

RESULTS

***Cotton growth and development*:** The effect of different row spacing and nitrogen application on the plant growth and development is shown in Table 2. Data revealed that maximum plant density was observed under the treatment of UNR, followed by narrow, as compared to conventional row spacing during both the years of trial. However, plant population per unit area was independent of nitrogen doses (Table 2A). Row spacing and nitrogen interacted significantly for plant height during year-I. Considerably more height was noted for the plant grown in conventional row spacing, treated with 150 kg N per ha. Plant height was significantly affected by nitrogen applications during the year-I. However, the situation was otherwise during the 2nd year (Table 2B). Cotton plants produced the highest number of nodes per plant in conventional row spacing, followed by narrow and UNR mode, respectively, during both the years of trial. Nitrogen application @ 120 kg ha^{-1}(control) enhanced the number of the node as compared to N @ 150 kg ha^{-1} during the second year. Nonetheless, the results were non-significant during the first year of the study (Table 2C). A significant interaction between cotton row spacing and nitrogen application on the number of squares plant^{-1} was depicted during both experimental years. The greater number of squares plant^{-1} was recorded in conventional spacing methods followed by narrow and UNR row spacing during years 2015 & 2016. Nitrogen application @ 120 kg ha^{-1}(control) produced more number of squares plant^{-1} in 2015 but during 2016 N @ 150 kg ha^{-1}surpassed control treatment (Table 2D). Maximum monopodial branches plant^{-1} in conventional had observed followed by the minimum in narrow spacing's methods and the least was in UNR and conventional spacing's during the year I and II, respectively. Nitrogen treatment described non-significant results but the maximum number of monopodial branches plant^{-1}was shown in the year-II (Table 2E). Plants under conventional sowing method produced the maximum number of sympodial branches per plant during both the years. On the other hand, applied treatment N @ 120 kg ha^{-1}(control) was resulted prominently maximum as per control treatment during the second year of the experiment (Table 2F). In case of the reproductive growth phase, the number of flowers plant^{-1} under conventional row was found to be the maximum, followed by narrow and UNR with N @ 150 kg ha^{-1}, compared to control (@ 120 kg ha^{-1}) during both the years (Table 2G).

***Cotton yield and yield attributes*:** Row spacing and nitrogen application interacted significantly for the number of open bolls plant^{-1}during both the years of trial. Plants under conventional row spacing's method produced the maximum number of open bolls plant^{-1} followed by narrow row spacing and UNR method, respectively. Application of nitrogen @ 150 kg ha^{-1} enhanced the number of open bolls plant^{-1}as compared to control N (@ 120 kg ha^{-1}) during the year I & II (Table 3A). The highest number of un-open bolls plant^{-1}was recorded in conventional row spacing, followed by narrow and UNR treatment, during both the years of study. Effect of nitrogen application was non-significantly better in the treatment of N @ 150 kg ha^{-1} during the 2nd year than 1st year of the trial (Table 3B). Average boll was non-significantly affected by row spacing and nitrogen doses during both the years (Table 3C). The impact of row spacing and nitrogen on ginning outturn was non-significant during both the years of study (Table 3E). Finally, the highest and the lowest seed cotton yield was observed in UNR and conventional method, respectively, during the year 2015 and 2016.

Table 2. Comparison effect of various row spacing methods on cotton growth and development.

	UNR		Narrow		Conventional		Mean	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**	**Year-I**	**Year-II**
(A) Plant populations acre^{-1}								
N_0	85367b	86967a	42243c	43398b	16234e	17212d	**47948**	**49192$_{NS}$**
N_1	86290a	86957a	41857d	43413b	16244e	17266c	**48130**	**49212**
Mean	***85829A***	***86962A***	***42050B***	***43406B***	***16239C***	***17239C***		
(B) Plant height (cm)								
N_0	70.47f	77.64d	82.20d	89.14bc	126.87b	143.16a	**93.178B**	**103.31**
N_1	74.20e	85.80cd	86.67c	95.38b	129.40a	140.38a	**96.756A**	**107.19**
Mean	**72.33C**	**81.72C**	**84.43B**	**92.26B**	**128.13A**	**141.77A**		
(C) Number of nodes plant^{-1}								
N_0	70.00c	86.53b	86.33b	101.13a	98.73a	105.23a	**86.222**	**97.633A**
N_1	69.33c	71.50c	83.87b	72.33c	102.33a	88.43b	**83.978**	**77.422B**
Mean	**69.67C**	**79.017C**	**85.10B**	**86.733B**	**100.53A**	**96.833A**		
(D) Number of squares plant^{-1}								
N_0	44.67e	45.87d	75.33c	77.23b	130.33b	132.43a	**85.278A**	**85.178B**
N_1	47.07d	48.63c	76.50c	77.60b	132.27a	133.43a	**83.444B**	**86.556A**
Mean	***45.87C***	***47.25C***	***75.92B***	***77.42B***	***131.30A***	***132.93A***		
(E) Monopodial branches plant^{-1}								
N_0	1.66d	3.97a	2.06bc	2.06bc	3.80a	1.71cd	**2.66**	**2.58**
N_1	1.40d	4.35a	2.33b	2.47b	4.26a	1.40d	**2.51**	**2.74**
Mean	***1.53C***	***4.16A***	***2.20B***	***2.27B***	***4.03A***	***1.55C***		
(F) Sympodial branches plant^{-1}								
N_0	29.743b	29.797b	31.733b	51.597a	46.600a	48.573a	**36.026**	**43.322A**
N_1	28.187b	33.293b	31.083b	32.663b	50.153a	30.837b	**36.474**	**32.264B**
Mean	***28.965B***	***31.545B***	***31.408B***	***42.130A***	***48.377A***	***39.705A***		
(G) Number of flowers plant^{-1}								
N_0	28.00f	31.33f	58.33d	61.00d	92.33b	96.67b	**59.556B**	**63.000B**
N_1	38.00e	43.00e	69.00c	74.00c	102.33a	110.00a	**69.778A**	**75.667A**
Mean	***33.00C***	***37.17C***	***63.667B***	***67.50B***	***97.33A***	***103.33A***		

Means sharing the different letters are significantly different from each other's @0.05%; UNR (Ultra Narrow Row spacing @ 15cm), Narrow (Narrow Row Spacing @ 30 cm), Conventional (Conventional Row Spacing @ 75 cm) N_0 (Control treatment as recommended application of Nitrogen @120 kg ha^{-1}), N_1 (Treatment as application of Nitrogen @150 kg ha^{-1}).

Nitrogen application @ 150 kg ha^{-1} produced the highest yield as compared to control (N @ 120 kg ha^{-1}) during both the years (Table 3D). The quality parameters like staple length, staple micronaire, fiber strength, fiber elongation, fiber fineness, and fiber uniformity were also improved non-significantly by row spacing and N application during both the years of study.

***Benefit-cost ratio* (*BCR*):** BCR indicated that crop grown in UNR spacing with N application @ 150 kg ha^{-1} was found to be highly profitable followed by narrow and conventional row spacing, respectively, during both the years (Table 4). Similarly, maximum net income was recorded in UNR system with 120 kg N ha^{-1}, as compared to conventional and narrow row spacing technique during both the years (Table 4).

Table 3. Comparison effect of various row spacing methods on cotton yield and yield attributes.

	UNR		Narrow		Conventional		Mean	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**	**Year-I**	**Year-II**
(A) Number of Open bolls plants^{-1}								
N_0	14.000d	18.000d	30.667c	35.667c	56.667b	59.667b	33.778B	37.778B
N_1	18.000d	22.667d	33.333c	37.333c	61.667a	70.000a	37.667A	43.333A
Mean	16.000C	20.333C	32.000B	36.500B	59.167A	64.833A		
(B) Number of Un-Open bolls plant^{-1}								
N_0	3.333c	5.000c	6.000bc	7.667bc	12.333a	14.667a	7.2222	9.1111
N_1	5.000c	7.667bc	7.333bc	9.000bc	10.667ab	12.333ab	7.6667	9.6667
Mean	4.167B	6.333B	6.667B	8.333B	11.500A	13.500A		
(C) Average boll weight (g)								
N_0	3.2200	3.9013	3.3000	3.4920	3.3700	3.7553	3.2967	3.7162
N_1	3.0967	3.2993	3.2733	3.3910	3.4200	3.6393	3.2633	3.4432
Mean	3.1583	3.6003	3.2867	3.4415	3.3950	3.6973		
(D) Cotton yield (Kg ha^{-1})								
N_0	4025.7b	4266.3b	3350.3d	3504.7d	2509.7f	2716.7e	3295.2B	3495.9B
N_1	4416.0a	4816.0a	3699.7c	3943.3c	2885.0e	3359.0d	3666.9A	4039.4A
Mean	4220.8A	4541.2A	3525.0B	3724.0B	2697.3C	3037.8C		
(E) Ginning Outturn (GOT) (%)								
N_0	36.257	36.484	36.220	36.284	36.310	36.438	36.262	36.402
N_1	36.283	36.351	36.273	36.312	36.263	36.336	36.273	36.333
Mean	36.270	36.417	36.247	36.298	36.287	36.387		

Means sharing the different letters are significantly different from each other's @ 0.05% UNR (Ultra Narrow Row spacing @ 15cm), Narrow (Narrow Row Spacing @ 30 cm), Conventional (Conventional Row Spacing @ 75 cm) N_0 (Control treatment as recommended application of Nitrogen @120 kg ha^{-1}), N_1 (Treatment as application of Nitrogen @150 kg ha^{-1})

Table 4. Economic analysis of various row spacing methods with nitrogen application in cotton.

Treatments	Total expenses (US$ ha^{-1})		Gross income (US$ ha^{-1})		Net income (US$ ha^{-1})		Benefit-Cost Ratio (BCR)	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
N_0 × UNR	1331.72	1331.72	5684.82	5685.82	4242.29	4243.30	3.94	3.94
N_1 × UNR	1442.52	1442.52	5386.89	5387.85	4055.17	4056.13	4.04	4.04
N_0 × Narrow	1480.31	1578.47	5740.09	5184.92	4259.77	3606.45	3.87	3.28
N_1 × Narrow	1578.47	1480.31	5183.63	5741.38	3605.15	4261.06	3.28	3.87
N_o × Conventional	1879.65	1879.65	5184.64	5185.55	3304.98	3305.90	2.75	2.75
N_1 × Conventional	1944.35	1944.35	5686.21	5687.50	3741.85	3743.14	2.92	2.92

UNR (Ultra Narrow Row spacing @ 15cm), Narrow (Narrow Row Spacing @ 30 cm), Conventional (Conventional Row Spacing @ 75 cm) N_0 (Control treatment as recommended application of Nitrogen @120 kg ha^{-1}), N_1 (Treatment as application of Nitrogen @150 kg ha^{-1}).

DISCUSSION

In UNR system of panting technique, plant populations per unit area with the application of N @ 150 kg ha^{-1}was better due to well managed and systematic row to row distance, which favors the proper growth and development of cotton crop (Nawaz *et al*., 2016). Conventional and narrow row spacing technique, with both levels of N (120 kg and 150 kg ha^{-1}) produced less seed cotton yield UNR in the sense of average plant density (Das *et al*., 2014). Plant height is a genetically controlled trait and in the case of UNR system, MQC was sprayed to limit the height and encourage the boll formation (Nichols *et al*., 2003). Application of growth inhibitor MQC under UNR system is an important strategy to suppress the height by shortening the number of nodes and inter-nodal distance which enhances the production of healthy cotton bolls (Khan *et al*., 2012). Due to the application of growth inhibitor, the number of squares per plant in UNR system were reduced under N application @ 150 kg ha^{-1} as compared to conventional and narrow row spacing techniques (John *et al*., 2006). Competition for space and light might be the reason for less number of squares in UNR and narrow spacing as compared to the conventional technique (Miko and Manga, 2008). Monopodial and sympodial branches are the primary indicators of vegetative growth and fruit formation. In the conventional row spacing, better fruit bearing might be attributed to the establishment of well-developed branching system due to the availability of excessive amount of nutrients, light, and space, as compared to UNR and narrow row technique of cotton planting. Reduction in the number of branches of UNR plants favors the utilization of photosynthates for reproductive growth phase in the form of boll formation, Cotton yield is directly related to the anthesis process and maximum flowering was observed in conventional row spacing, which might be due to excessive utilization of natural resources, as compared with UNR and narrow row spacing method (Girma *et al*., 2007).

Final yield and yield components indicate the cumulative response of cotton plants to the applied treatments and agronomic practices during crop growing period (Nadeem *et al*., 2010). The conventional method of planting favored the transport of photosynthetic assimilates for the formation of the healthy number of opened and un-opened bolls in the available experimental conditions. Production of the maximum number of bolls in conventional method might be due to the more space available to plants, as compared with UNR and narrow row planting system (Ali *et al*., 2009). Cotton yield potential is directly proportioned to the weight of boll and similar results in the applied treatments presented the genetic behavior of cultivars during both years of the experiment (Jost and Cothren, 2000). Higher seed cotton yield in UNR is attributed to more number of bolls per unit area, as compared to the conventional row spacing method. In this way, the loss of final seed cotton yield was compensated by higher plant density under UNR technique, in comparison with other treatments (Muhammad *et al*., 2002). Average Ginning outturn was not affected by different sowing techniques, which might be due to similar genetic makeup (Heap, 2000). The improvement in fiber quality traits like staple length, staple micronaire, fiber strength, fiber fineness, and fiber uniformity could be attributed to proper moisture availability and translocation of photosynthates to reproductive organs under UNR planting system (John *et al*., 2006).

Cotton plants raised under UNR technique increased the economic outcomes under both conditions of applied nitrogen doses in the experiment years I & II (Das *et al*., 2014). More than four times BCR in UNR proposed that it is a profitable environment-friendly and easily practicable technique for cotton production (Farooq and Siddique, 2015).

***Conclusion*:** Planting of cotton through ultra-narrow row spacing's with the addition of nitrogen in the form of urea (Nitrogen @ 150 kg ha^{-1}) was highly cost-effective technique with increasing benefit-cost ratio by maximizing the plant population and seed cotton yield. The findings of this study suggest the cotton growers of the Southern Punjab, Pakistan to adopt newly emerging ultra-narrow row spacing's technique for profitable cotton production.

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