Supplemental application of phosphorus improves yield, quality and net returns of *Gossypium hirsutum*

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Abstract
Cotton is a white gold due to its high economic values. Phosphorus is an important constituent that is essential for seed development and yield. Efficient use of phosphorus plays a significant role to achieve quality production in form of yield to overcome the problems. A field study comprised of four phosphorus levels viz. (P₀ = 0 kg ha⁻¹, P₁ =50 kg ha⁻¹, P₂ =100 kg ha⁻¹, P₃ =150 kg ha⁻¹) and cultivars viz CIM-598, MNH-886, CIM-616, CIM-612, FH-LALAZAR during 2015 and 2016. Application of phosphorous significantly improved quality and yield in terms of plant height (161.33 cm), bolls number plant⁻¹ (31.667), number of nodes plant⁻¹ (49.000), boll weight (2.200 g), seed cotton harvest (3481.3 %), seed cotton yield (2928.3 kg ha⁻¹), seed lint yield (56.667 kg ha⁻¹), biological yield (0.960 kg ha⁻¹), and ginning out turn (0.0227 %). Significant increase was observed for leaf area index (0.980 m²), crop growth rate (1.416 g m⁻² day⁻¹), net assimilation rate (1.480 g m⁻² day⁻¹), leaf area duration (871.33), phosphorus concentration (0.270), fiber uniformity (70.667), staple length (47.500 mm), fiber strength (33.500 tppsi) and micronair (5.166 µg inch⁻¹). Phosphorus spray of 150 kg ha⁻¹ is more suitable for greater cotton production.

Keywords: Cotton; Cotton quality; Economic benefits; Fiber uniformity; Phosphorus

Introduction
Cotton *Gossypium hirsutum* L. belongs family Malvaceae and comprised of approximately 50 species [1]. Cotton is a unique natural fiber provides medicinal compounds, vegetable oil, organic matter and energy sources to fertile soil, meal and hull for livestock feed and industrial lubricants [2].

Deficiency of phosphorus is major problem in calcareous soils all over the world specially Pakistan [3]. Deficiency of phosphorus decreased in plant growth, photosynthesis and yield [4]. Phosphorus demand has been increased due to the maximum production of cultivars as well as sufficient increase of growth as well as development due to regulation of photosynthesis with rise of CO₂ concentrations [3]. However, evaluation of carbon dioxide increased yield, photosynthesis mechanism as well as plant growth. However, phosphorus has a major nutrient for plant response to elevated carbon dioxide [3, 5]. Phosphorus deficiency resulting in reduction of dry matter and poor development of cotton roots [6, 7]. While
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the minimization of phosphorus impact on cotton plants which could be retained 35% phosphorus in its roots, compared with 14% in phosphorus sufficient cotton [8]. Moreover, phosphorous utilization occurred maximum in growing season when the root system is fully developed [9].

Phosphorus fertilizer application mainly depends on fertilizer application of phosphorus, type of soil, agronomic implications and geographical site of cultivated crop mainly resulting in improvement of crop productivity [5, 10]. Different types of genotypes have different efficiency to perform in absorbing fertilizer efficiently due to difference in genetic makeup [11]. The important genetically differences among cotton cultivars can be exploited for breeding efficient cultivars because of fertilizer enhances efficiency [12]. It would preferable to select and identify the important traits between various cotton cultivars that are directly relate to phosphorus efficiency.

Many previous studies have been carried out to investigate the deficiency of phosphate on cotton growth as well as physiological process due to the projected atmospheric carbon dioxide conditions which are limited [8]. So, the maximum root assimilation growth due to stress of phosphorus of cotton could be conflicted on a significant advantage in soluble phosphorus acquisition by cotton. Therefore, suitable cultivars selection according to the prevailing conditions of the region along with important management practices is even more importance for cotton production, although high yield potential is a principal concern.

Materials and methods

Experimental details

Investigate the response of various cotton cultivars to phosphorus application during 2015-2016 (Fig. 1). Eco-meteorological data of experimental site was listed below. Experimental treatments comprises of four phosphorus levels viz. To= 0 kg ha⁻¹, T₁= 50 kg ha⁻¹, T₂= 100 kg ha⁻¹, T₃= 150 kg ha⁻¹ and five cultivars viz. CIM- 598, MNH - 886, CIM - 616, CIM- 612, FH- LALAZAR. The preparation of seed bed cotton was sown by having row -row distance of 75 cm as well as plant – plant distance of 25 cm during 28 May 2015 and 31 May 2016. Urea fertilizers 36 kg ha⁻¹ applied as per standard role and four Phosphorous levels (0, 50, 100 and 150 kg ha⁻¹), respectively. Randomized complete block design (RCBD) was applied along with three replications. Irrigation as well as crop protection needs were performed as per requirement of the crop. Harvesting was done on 05-11-2015 to 13-11-2016 with the picking interval of 2 weeks.

Observations recorded

Agronomic traits

Plant height was determined from five collected plants through measuring scale. Same plants were used to measure number of bolls per plant. One hundred good open bolls were choose for picking to get 100 boll weights (g) from each treatment. Seed cotton yield was recorded after picking and then weighed to get the yield per hectare (kg ha⁻¹). Ginning out turn (%) was calculated through weighing cotton lint and cotton seed. According to previous studies [13, 14].

Allometry traits

Leaf area index was measured by dividing leaf area over the land area. Crop growth rate was measured by collected weighed samples of 20, 40, 50 g of green leaves, stalks and bolls which were gained from different stages of crop growth and were dried in the oven at 80 °C. Hunt [20] gave the formula to calculate net assimilation rate.

Statistical analysis

The statistical software, Statistix 8.1 (Tallahassee Florida, USA) was used to examine two years collected data. Due to two factors; cultivars and treatment three-way analysis of variance were applied. Year interaction was non-significant and did not described. Means were separated
through LSD test at 5% level of probability.

**Results**

Descriptive statistics for individual effect of cultivars, phosphorus levels and their interactive effects was presented in the (Table 1). Regarding the individual effect of cultivars, larger plant height was calculated in cultivars MNH-886 and CIM-616, while smaller plant height was measured in cultivars CIM-616 and FH-Lalazar. Number of bolls plant\(^{-1}\) were higher in cv. CIM-616, while lower was in CIM-598 and FH-Lalazar. CIM-616 had the maximum number of nodes plant\(^{-1}\) and boll weight as compared to all other studied traits. The performance of all the studied cultivars was similar for the seed cotton yield and seed cotton harvest. The highest lint yield was measured in MNH-886, while lowest was in CIM-616. CIM-612 had the highest biological yield, followed by CIM-616 than all the studied cultivars. FH-Lalazar, followed by CIM-616 and CIM-598 had the highest ginning out turn as compared to other cultivars (Table 2). CIM-616 had the highest leaf area index, crop growth rate and micronair, while the lowest leaf area index, crop growth rate, net assimilation rate and leaf area duration was in FH-Lalazar (Table 3). MNH-886 had the maximum net assimilation rate, leaf area duration, phosphorus concentration, fiber uniformity, staple length and fiber strength (Table 3).

Regarding the effect of phosphorus on agronomic and yield related traits, phosphorus concentration (150 kg ha\(^{-1}\)) showed the better results as compared to other concentrations. The highest plant height, number of boll plant\(^{-1}\), number of nodes plant\(^{-1}\), boll weight, seed cotton yield, lint yield, biological yield, seed cotton harvest and ginning out turn were recorded during phosphorus application as 150 kg ha\(^{-1}\) than other application doses (Table 4). Individual effect of phosphorus on physiological and fiber quality traits were presented (Table 5). Phosphorus application (150 kg ha\(^{-1}\)) significantly enhanced leaf area index, crop growth rate, net assimilation rate, leaf area duration, phosphorus concentration, fiber uniformity, staple length, fiber strength and micronair (Table 5).

As regards, the interaction of cultivars and phosphorus effect on agronomic and yield related traits, the highest plant height was recorded during (P\(_3\) × V\(_3\)) and (P\(_3\) × V\(_3\)), while the lowest plant height was measured during (P\(_0\) × V\(_4\)) and (P\(_0\) × V\(_5\)) as compared to other genotypes. The maximum number of bolls plant\(^{-1}\) was counted in (P\(_3\) × V\(_3\)), while the minimum number of bolls plant\(^{-1}\) was calculated in (P\(_0\) × V\(_5\)) and (P\(_0\) × V\(_1\)). Number of nodes plant\(^{-1}\) were not significantly varied in the current studied. Boll weight was higher in (P\(_3\) × V\(_1\)), (P\(_3\) × V\(_2\)), (P\(_0\) × V\(_5\)) and (P\(_3\) × V\(_5\)), while lower boll weight was in (P\(_0\) × V\(_3\)), followed by (P\(_0\) × V\(_1\)), (P\(_0\) × V\(_2\)), (P\(_1\) × V\(_3\)) and (P\(_0\) × V\(_4\)). The maximum seed cotton yield was in (P\(_3\) × V\(_2\)) and (P\(_3\) × V\(_4\)), while the minimum was measured in (P\(_0\) × V\(_4\)). Lint yield was higher in (P\(_3\) × V\(_2\)), followed by (P\(_3\) × V\(_4\)). However, the lowest was measured in (P\(_0\) × V\(_5\)) and (P\(_1\) × V\(_5\)). The highest biological yield was measured in (P\(_3\) × V\(_4\)), followed by (P\(_2\) × V\(_4\)), while the lowest was calculated in (P\(_0\) × V\(_2\)) and (P\(_1\) × V\(_2\)). Phosphorus application and cultivars were not showed significant effect on ginning out turn (Table 6). Effect of phosphorus on physiological and fiber quality traits of cotton cultivars were presented (Table 7). The maximum leaf area index was measured in (P\(_2\) × V\(_3\)), while the minimum leaf area index was measured in (P\(_0\) × V\(_1\)), followed by (P\(_3\) × V\(_5\)). Crop growth rate and net assimilation rate were significantly higher in (P\(_3\) × V\(_4\)), while lower were measured in (P\(_0\) × V\(_1\)). The highest leaf area duration was measured in (P\(_3\) × V\(_2\)), while the lowest was calculated in (P\(_0\) × V\(_3\)). The highest phosphorus concentration was calculated (P\(_1\) × V\(_3\)) and (P\(_3\) × V\(_5\)), followed by (P\(_0\) × V\(_5\)), (P\(_2\) × V\(_5\)), (P\(_3\) × V\(_3\)), (P\(_2\) × V\(_2\)) and (P\(_2\) × V\(_5\)). However, the
lowest phosphorus concentration was measured in (P2 × V3). Fiber quality traits i.e. fiber uniformity, staple length and fiber strength were significantly higher in (P3 × V2). The highest micronair was recorded in (P3 × V3) than all other interactions of the current study (Table 7). Detailed description of cost benefit ratio was evaluated as presented in the (Table 8).

**Discussion**

Plant height was the highest in MNH-886 and CIM-616 treated with phosphorus 150 kg ha\(^{-1}\) (T3), while the lowest was in CIM-612, followed by FH-LALAZAR as control (T0). Current work is accordance to previous results because these exhibited a positive reaction of phosphorus supplement in cotton crop [15]. Number of bolls per plant is an anticipated trait that is involved in seed cotton yield. Spray of phosphorus concentration (150 kg ha\(^{-1}\)) significantly improved the number of bolls per plant than controlled treatment. Among micronutrients i.e. phosphorus is considered to be important for cell enlargement as well as for meristematic tissue development. Furthermore, phosphorus is causing an encouraging effect on flower buds as well as plant bolls. These consequences are in line with earlier consequences as described [15, 16]. Number of nodes per plant was the greatest in cultivar CIM-616 treated with phosphorus 150 kg ha\(^{-1}\) (T3) and the minimum numbers of nodes were in four cultivars such as CIM-612, CIM-598, MNH-886 and FH-LALAZAR without any treatment of phosphorus (T0). These results correlated with [17]. Micronutrients especially phosphorus is also meaningfully increased boll weight than controlled treatment, as treatment rate was improved up to 150 kg ha\(^{-1}\) [18]. However, photosynthetic balance as well as stomatal regulation was limited. However, carbon dioxide was found to be decreased when phosphorus deficiency occurs. Present results are in accordance with the findings of previous studies as obtained by Sawan *et al.* [19]. Phosphorus is macronutrient significantly involved in stimulation of flowering of cotton cultivars. Therefore, current study indicated that increase of flowering and boll development provides higher crop yield to farmers. Earlier results confirmed that phosphorus had significantly enhances seed cotton yield [16, 20]. Furthermore, present consequences were also agreed by earlier research [21]. Lint and biological yield as well as seed cotton harvest was the maximum from the highest concentration applied (150 kg ha\(^{-1}\)). However, current findings were in accordance as stated Sawan *et al.* [19] because good nutrient response as well as their ease of use resulting in initiation as well as formation of higher number of fibers per seed. Ginning out turn was enhanced due to higher phosphorus concentration. Environmental factors, different biotic and abiotic stresses and genetic make-up are major cause of variation in production of different agronomic crops [2]. Leaf area index and crop growth rate were the maximum in CIM-616 and phosphorus treated with 100 kg ha\(^{-1}\) (T2), while leaf area index as well as crop growth rate was the minimum in cultivar FH-LALAZAR treated as control (T0). Net assimilation rate was the maximum in cultivar CIM-612 (1.480) and the phosphorus level was treated as 150 kg ha\(^{-1}\) (T3). Leaf area duration and phosphorus concentration were the highest in cultivar MNH-886 (871.33) which treated with phosphorus level of 150 kg ha\(^{-1}\) (T3) of phosphorus. The maximum fiber uniformity, staple length, fiber strength were in cultivar MNH-886 (70.667) and treatment was 150 kg ha\(^{-1}\) (T3). Micronair value was the maximum in cultivar CIM-616 (5.166) and phosphorus level was 150 kg ha\(^{-1}\). Current study in line to previous work because supplemental application of phosphorus improves yield, quality and net returns of cotton [22-24].
Figure 1. Eco-meteorological data of Multan, Punjab (Pakistan) during 2015 (A & C) and during 2016 (B & D)
Table 1. Significance level of agronomic, yield and fiber related traits as affected by cultivars and phosphorus concentrations

| Parameters                          | Cotton cultivars | Phosphorus application | Cotton cultivars × phosphorus application |
|------------------------------------|------------------|-------------------------|------------------------------------------|
| Plant height (cm)                  | 352.500**        | 464.222**               | 7.167**                                  |
| Number of bolls plant⁻¹            | 53.8917**        | 77.2667**               | 1.2806**                                 |
| Number of nodes plant⁻¹            | 44.2667**        | 46.8167**               | 2.4000ns                                 |
| Boll weight (g)                    | 0.39208**        | 1.12044**               | 0.19586**                                |
| Lint yield (kg ha⁻¹)               | 552.442**        | 118.333**               | 16.264**                                 |
| Biological yield (kg ha⁻¹)         | 0.06262**        | 0.18012**               | 0.00310**                                |
| Seed cotton harvest (%)            | 156.659**        | 200.623ns               | 5.546**                                  |
| Ginning out turn (%)               | 2.244 **         | 1.350ns                 | 3.711ns                                  |
| Leaf area index                    | 0.20759**        | 0.02123**               | 0.01455**                                |
| Crop growth rate (g m⁻² day⁻¹)     | 0.31000**        | 0.17217**               | 0.24411**                                |
| Net assimilation rate (g m⁻² week⁻¹)| 0.01003**      | 0.01784**               | 0.00232**                                |
| Leaf area duration (days)          | 0.01003**        | 0.01784**               | 0.00232**                                |
| Phosphorus concentration           | 0.20759**        | 0.02123**               | 0.01455**                                |
| Fiber uniformity                   | 589.142**        | 466.000**               | 71.986**                                 |
| Staple length (mm)                 | 651.608**        | 125.022**               | 34.953**                                 |
| Fiber strength (tppsi)             | 7.889ns          | 105.933**               | 34.194**                                 |
| Micronair (µ inch⁻¹)               | 0.29142**        | 0.16950**               | 0.24411**                                |

NS = non-significant; * = significant (P <0.05) and ** = highly significant (P <0.01)
Table 2. Individual effect of cultivars on agronomic and yield related traits

| Cultivars | Plant height (cm) | Number of bolls/plant | Number of nodes/plant | Boll weight (g) | Seed cotton yield (kg ha\(^{-1}\)) | Lint yield (kg ha\(^{-1}\)) | Biological yield (kg ha\(^{-1}\)) | Seed cotton harvest (%) | Ginning out turn (%) |
|-----------|-------------------|-----------------------|------------------------|-----------------|-----------------------------------|-----------------------------|--------------------------|------------------------|---------------------|
| CIM-598   | 146.67 b          | 23.00 c               | 40.58 b                | 1.49 b          | 2289.0 a                         | 41.41 c                    | 0.83 ab                  | 22 a                   | 0.020 ab            |
| MNH-886   | 152.50 a          | 25.66 b               | 40.58 b                | 1.45 b          | 2138.8 a                         | 53.50 a                    | 0.58 c                   | 21 a                   | 0.017 c             |
| CIM-616   | 152.50 a          | 28.03 a               | 44.91 a                | 1.20 c          | 2161.9 a                         | 39.33 d                    | 0.81 ab                  | 21 a                   | 0.020 ab            |
| CIM-612   | 141.67 c          | 24.75 b               | 40.75 b                | 1.48 b          | 2354.1 a                         | 47.33 b                    | 0.89 a                   | 23 a                   | 0.019 b             |
| FH-lalazar| 141.67 c          | 23.00 c               | 40.58 b                | 1.70 a          | 2590.5 a                         | 36.58 e                    | 0.79 b                   | 25 a                   | 0.021 a             |

Mean values sharing similar letter(s) in a column are statistically non-significant at p = 0.05 (LSD test)

Table 3. Individual effect of cultivars on physiological and fiber quality traits

| Cultivars | Leaf area index | Crop growth rate (g m\(^{-2}\) day\(^{-1}\)) | Net assimilation rate (g m\(^{-2}\) week\(^{-1}\)) | Leaf area duration (days) | Phosphorus concentration | Fiber uniformity | Staple length (mm) | Fiber strength (tppsi) | Micronair (µ inch\(^{-1}\)) |
|-----------|-----------------|---------------------------------------------|--------------------------------------------------|---------------------------|-------------------------|------------------|-------------------|------------------------|--------------------------|
| CIM-598   | 0.58 c          | 4.28 bc                                     | 1.31 c                                           | 546.5 c                   | 40.25 c                 | 40.25 c          | 21.75 c           | 24.83 c                | 4.28 bc                  |
| MNH-886   | 0.70 b          | 4.30 bc                                     | 1.38 a                                           | 760.1 a                   | 48.16 a                 | 58.16 a          | 36.16 a           | 30.66 a                | 4.30 bc                  |
| CIM-616   | 0.80 a          | 4.63 a                                      | 1.37 ab                                          | 461.7 d                   | 45.83 b                 | 45.83 b          | 19.58 d           | 24.50 c                | 4.63 a                   |
| CIM-612   | 0.81 a          | 4.25 b                                      | 1.36 b                                           | 637.5 b                   | 45.75 b                 | 45.75 b          | 24.50 b           | 28.16 b                | 4.25 b                   |
| FH-lalazar| 0.51 d          | 4.23 c                                      | 1.32 c                                           | 404.2 e                   | 42.00 c                 | 42.00 c          | 17.33 e           | 23.58 c                | 4.23 c                   |

Mean values sharing similar letter(s) in a column are statistically non-significant at p = 0.05 (LSD test)
Table 4. Individual effect of phosphorus on agronomic and yield related traits

| Treatment       | Plant height (cm) | Number of bolls/plant | Number of nodes/plant | Boll weight (g) | Seed cotton yield (kg ha\(^{-1}\)) | Lint yield (kg ha\(^{-1}\)) | Biological yield (kg ha\(^{-1}\)) | Seed cotton harvest (%) | Ginning out turn (%) |
|-----------------|-------------------|-----------------------|-----------------------|-----------------|-------------------------------------|----------------------------|-------------------------------|-----------------------|----------------------|
| Control (P\(_0\)) | 140.73 d          | 22.33 d               | 39.26 c               | 1.30 b          | 2116.9 a                           | 40.40 c                    | 0.73 b                         | 21 a                  | 0.018 a              |
| 50 kg/ha (P\(_1\)) | 145.13 c          | 24.13 c               | 40.93 b               | 1.30 b          | 2221.3 a                           | 43.00 b                    | 0.75 b                         | 22 a                  | 0.018 a              |
| 100 kg/ha (P\(_2\)) | 149.13 b          | 25.40 b               | 42.46 a               | 1.38 b          | 2221.4 a                           | 43.93 b                    | 0.80 ab                        | 22 a                  | 0.018 a              |
| 150 kg/ha (P\(_3\)) | 153.87 a          | 27.73 a               | 43.26 a               | 1.47 a          | 2667.9 a                           | 47.29 a                    | 0.83 a                         | 26 a                  | 0.019 a              |

Mean values sharing similar letter(s) in a column are statistically non-significant at p = 0.05 (LSD test)

Table 5. Individual effect of phosphorus on physiological and fiber related traits

| Treatment       | Leaf area index | Crop growth rate (g m\(^{-2}\) day\(^{-1}\)) | Net assimilation rate (g m\(^{-2}\) week\(^{-1}\)) | Leaf area duration (days) | Phosphorus concentration | Fiber uniformity | Staple length (mm) | Fiber strength (tppsi) | Micronair (µ inch\(^{-1}\)) |
|-----------------|-----------------|---------------------------------------------|-----------------------------------------------------|---------------------------|-------------------------|-------------------|---------------------|------------------------|--------------------------|
| Control (P\(_0\)) | 0.64 c          | 4.24 b                                       | 1.31 d                                               | 495.9 d                   | 41.00 c                 | 41.00 c           | 20.33 d             | 24.73 b                | 4.24 b                   |
| 50 kg ha\(^{-1}\) (P\(_1\)) | 0.66 b          | 4.32 ab                                      | 1.33 c                                               | 538.1 c                   | 44.80 b                 | 44.80 b           | 23.40 c             | 25.46 b                | 4.32 ab                  |
| 100 kg ha\(^{-1}\) (P\(_2\)) | 0.71 a          | 4.46 a                                       | 1.35 b                                               | 582.6 b                   | 45.60 b                 | 45.60 b           | 24.40 b             | 27.20 a                | 4.46 a                   |
| 150 kg ha\(^{-1}\) (P\(_3\)) | 0.71 a          | 4.46 a                                       | 1.39 a                                               | 631.4 a                   | 54.20 a                 | 54.20 a           | 27.33 a             | 28.00 a                | 4.46 a                   |

Mean values sharing similar letter(s) in a column are statistically non-significant at p = 0.05 (LSD test)
Table 6. Interactive effect of phosphorus and cotton cultivars on agronomic and yield related traits

| Treatment | Plant height (cm) | Number of bolls/plant | Number of nodes/plant | Boll weight (g) | Seed cotton yield (kg ha⁻¹) | Lint yield (kg ha⁻¹) | Biological yield (kg ha⁻¹) | Seed cotton harvest (%) | Ginning out turn (%) |
|-----------|------------------|-----------------------|----------------------|----------------|-----------------------------|---------------------|--------------------------|----------------------|----------------------|
| PoV1      | 140.67 h         | 20.500 h              | 38.667 h             | 1.133 gh       | 2091.3 de                  | 39.00 g             | 0.800 c-f                | 880.0 a-c           | 0.021 bc             |
| P1V1      | 144.67 f         | 22.000 g              | 40.500 fg             | 1.333 de       | 2174.7 d                   | 41.333 f            | 0.832 c-e                | 2174.7 b-d          | 0.020 bc             |
| P2V1      | 148.83 d         | 23.833 f              | 41.667 de             | 1.400 cd       | 2428.3 bc                  | 41.333 f            | 0.830 c-e                | 2428.3 a-d          | 0.020 bc             |
| P3V1      | 152.83 c         | 26.000 d              | 41.833 d             | 2.133 a        | 2471.7 bc                  | 44.500 e            | 0.865 b-d                | 2471.7 a-d          | 0.019 bc             |
| P0V2      | 144.83 f         | 24.000 f              | 38.667 h             | 1.150 f-h      | 1923.7 fg                  | 48.333 d            | 0.527 h                  | 2928.3 ab            | 0.011 e              |
| P1V2      | 149.33 d         | 25.833 de             | 40.667 e-g           | 1.333 de       | 1831.3 gh                  | 54.167 c            | 0.492 h                  | 1831.3 cd            | 0.009 f              |
| P2V2      | 155.17 b         | 26.000 d              | 41.667 de             | 1.333 de       | 1903.7 fg                  | 55.333 bc           | 0.665 g                  | 1903.7 b-d          | 0.012 e              |
| P3V2      | 161.33 a         | 27.167 c              | 41.833 d             | 2.083 a        | 2928.3 a                   | 56.667 d            | 0.6667 g                 | 1923.7 b-d          | 0.012 e              |
| P0V3      | 144.83 f         | 25.000 e              | 41.667 de             | 1.033 h        | 2027.7 ef                  | 37.667 hi           | 0.790 d-f                | 2027.7 b-d          | 0.020 a-c            |
| P1V3      | 149.33 d         | 27.667 bc             | 43.500 c             | 1.200 e-h      | 2350.7 e                   | 39.500 g            | 0.840 c-e                | 2350.7 b-d          | 0.021 ab             |
| P2V3      | 155.17 b         | 28.500 b              | 45.833 b             | 1.366 de       | 2128.0 de                  | 39.333 g            | 0.801 c-f                | 2128.0 b-d          | 0.020 bc             |
| P3V3      | 161.33 a         | 31.667 a              | 49.000 d             | 1.283 d-g      | 2174.7 d                   | 41.667 f            | 0.830 c-e                | 2174.7 b-d          | 0.019 bc             |
| P0V4      | 136.17 i         | 22.000 g              | 38.500 h             | 1.200 e-h      | 1648.01 j                  | 41.000 f            | 0.828 c-e                | 2361.7 b-d          | 0.020 bc             |
| P1V4      | 141.00 h         | 23.500 f              | 40.333 g             | 1.316 d-f      | 2495.0 b                   | 44.167 e            | 0.866 b-d                | 2495.0 a-d          | 0.019 bc             |
| P2V4      | 143.00 g         | 25.333 de             | 41.500 d-f           | 1.550 c        | 2361.7 c                   | 48.333 d            | 0.926 ab                 | 2878.3 a-c          | 0.019 cd             |
| P3V4      | 146.33 e         | 28.000 bc             | 42.333 d             | 1.833 b        | 2878.3 a                   | 55.667 ab           | 0.960 a                  | 1648.0 d            | 0.017 d              |
| P0V5      | 136.50 i         | 20.333 h              | 38.667 h             | 2.050 a        | 1698.0 ij                  | 36.167 j            | 0.730 fg                 | 1698.0 d            | 0.020 bc             |
| P1V5      | 141.17 h         | 22.167 g              | 40.667 e-g           | 1.333 de       | 1763.0 h-j                 | 36.167 j            | 0.766 ef                 | 1763.0 d            | 0.021 ab             |
| P2V5      | 143.00 g         | 23.667 f              | 41.667 de           | 1.333 de       | 1801.3 g-i                | 36.667 ij           | 0.8233 c-e              | 1801.3 d            | 0.0227 a             |
| P3V5      | 146.67 e         | 26.167 d              | 42.167 d            | 2.200 a        | 1814.7 g-i                | 38500 gh            | 0.880 a-c               | 3481.3 a            | 0.022 a              |

Mean values sharing similar letter(s) in a column are statistically non-significant at p = 0.05 (LSD test)
Table 7. Effect of phosphorus on physiological and fiber quality traits of cotton cultivars

| Treatment | Leaf area index | Crop growth rate (g m² day⁻¹) | Net assimilation rate (g m² week⁻¹) | Leaf area duration (days) | Phosphorus concentration | Fiber uniformity | Staple length (mm) | Fiber strength (tppsi) | Micronair (µ inch⁻¹) |
|-----------|----------------|-------------------------------|-----------------------------------|--------------------------|--------------------------|-----------------|-----------------|---------------------|---------------------|
| P0V₁      | 0.558 k        | 0.725 o                      | 0.768 mn                          | 492.67 g                 | 0.185 gh                 | 39.667 gh       | 20.000 g        | 24.333 de           | 4.066 f             |
| P1V₁      | 0.5700 j       | 0.751 n                      | 1.315 h                           | 515.67 f                 | 0.196 e-h                | 39.333 h        | 20.333 fg        | 25.000 de           | 4.166 ef            |
| P2V₁      | 0.590 i        | 0.785 m                      | 1.331 fg                          | 584.67 e                 | 0.201 d-h                | 40.500 f-h      | 22.833 de        | 25.833 cd           | 4.416 cd            |
| P3V₁      | 0.618 h        | 0.825 l                      | 1.336 f                           | 594.67 de                | 0.205 c-h                | 41.667 e-g      | 24.000 d         | 24.333 de           | 4.500 c             |
| P0V₂      | 0.680 g        | 0.903 k                      | 1.330 fg                          | 613.33 d                 | 0.220 b-g                | 43.500 e         | 25.833 c         | 27.167 c             | 4.750 b             |
| P1V₂      | 0.681 g        | 0.940 j                      | 1.380 d                           | 755.67 c                 | 0.2250 b-f               | 57.333 c         | 35.333 b         | 29.000 b             | 4.066 f             |
| P2V₂      | 0.711 f        | 0.993 hi                     | 1.398 c                           | 805.33b                  | 0.231 a-e                | 62.000 b         | 36.500 b         | 33.500 a             | 4.200 ef            |
| P3V₂      | 0.743 e        | 1.056 c                      | 1.421 b                           | 871.33 a                 | 0.241 a-e                | 70.667 a         | 47.500 a         | 33.500 a             | 4.250 de            |
| P0V₃      | 0.768 cd       | 1.026 ef                     | 1.336 f                           | 415.33 hi                | 0.248 ab                 | 42.33 ef         | 17.667 h         | 23.333 e             | 4.266 de            |
| P1V₃      | 0.776 c        | 1.050 cd                     | 1.350 e                           | 430.00 h                 | 0.270 a                  | 45.667 d         | 20.833 fg        | 24.667 de           | 4.416 cd            |
| P2V₃      | 0.980 a        | 1.361 b                      | 1.388 cd                          | 494.33 fg                | 0.178 h                  | 40.000 gh        | 20.333 fg        | 25.000 de           | 4.733 b             |
| P3V₃      | 0.708 f        | 1.003 gh                     | 1.413 b                           | 512.33 fg                | 0.186 f-h                | 56.000 c         | 21.333 f         | 25.667 cd           | 5.166 a             |
| P0V₄      | 0.740 e        | 0.983 i                      | 1.330 fg                          | 588.00 e                 | 0.190 f-h                | 40.333 f-h       | 22.667 e         | 25.667 cd           | 4.400 cd            |
| P1V₄      | 0.765 d        | 1.016 fg                     | 1.331 fg                          | 593.00 de                | 0.201 d-h                | 41.667 e-g       | 24.000 d         | 25.667 cd           | 4.500 c             |
| P2V₄      | 0.776 c        | 1.038 de                     | 1.333 f                           | 611.67 d                 | 0.218 b-g                | 43.333 e         | 25.667 c         | 29.000 b             | 4.733 b             |
| P3V₄      | 0.956 b        | 1.416a                       | 1.480 a                           | 755.67 c                 | 0.236 a-d                | 57.667 c         | 25.667 c         | 32.33 a              | 4.066 f             |
| P0V₅      | 0.4733 n       | 0.615 q                      | 1.298 i                           | 372.00 j                 | 0.230 b-e                | 39.667 gh        | 16.000 i         | 23.667 e             | 4.200 ef            |
| P1V₅      | 0.5117 m       | 0.676 p                      | 1.321 gh                          | 406.33 i                 | 0.240 a-d                | 40.500 f-h       | 17.167 hi        | 23.333 e             | 4.150 ef            |
| P2V₅      | 0.531 l        | 0.710 o                      | 1.336 f                           | 417.00 hi                | 0.250 ab                 | 43.167 e         | 17.500 h         | 23.500 e             | 4.283 de            |
| P3V₅      | 0.565 jk       | 0.768 mm                     | 1.355 e                           | 431.67 h                 | 0.270 a                  | 45.667 d         | 19.833 g         | 24.667 de           | 4.400 cd            |

Mean values sharing similar letter(s) in a column are statistically non-significant at p = 0.05 (LSD test)
Table 8. Role of phosphorus foliar application on benefit cost ratio (BCR) of cotton 2015 & 2016

| Years | Treatments | Yield (kg ha⁻¹) | Value (Rs ha⁻¹) | Stick value (Rs ha⁻¹) | Gross value (Rs ha⁻¹) | Total cost (Rs ha⁻¹) | Net return (Rs ha⁻¹) | BCR |
|-------|------------|----------------|----------------|----------------------|----------------------|---------------------|---------------------|-----|
| 2015  | Control (P₀) | 2116.9         | 148183         | 8000                 | 156183               | 109950              | 46233               | 1.42 |
|       | 50 kg ha⁻¹ (P₁) | 2221.3         | 155491         | 8000                 | 163491               | 110550              | 52941               | 1.47 |
|       | 100 kg ha⁻¹ (P₂) | 2221.4         | 155498         | 10000                | 165498               | 110950              | 54548               | 1.49 |
|       | 150 kg ha⁻¹ (P₃) | 2667.9         | 186753         | 10000                | 196753               | 112000              | 84753               | 1.75 |
| 2016  | Control (P₀) | 1714.7         | 128602.5       | 8000                 | 136602.5             | 106550              | 30052.5             | 1.28 |
|       | 50 kg ha⁻¹ (P₁) | 1778.0         | 133350         | 8000                 | 141350               | 107400              | 33950               | 1.31 |
|       | 100 kg ha⁻¹ (P₂) | 1818.0         | 136350         | 10000                | 146350               | 109540              | 36810               | 1.33 |
|       | 150 kg ha⁻¹ (P₃) | 1814.7         | 136102.5       | 10000                | 146102.5             | 108950              | 37152.5             | 1.34 |

BCR = benefit-cost ratio

Conclusion
Excess uses of nutrients over optimum level affects the economy of farmers. In respect to observe the concentration of fertilization that were supplemented to crops. Hence, it is very compulsory to improve endorsement programs that will mentioned the fixed fertilizer doses according to requirements of cotton crop. Present study concluded that the highest rate of phosphorus increase the cotton production and also increase the farmer’s economy. Current study encourages the optimum use of phosphorus to avoid the excessive use of phosphors which leading higher input costs for farmer. Present study is also meaningful to improve the endorsement programs that will appropriately determine fertilizer supplements according to other crop needs.

Authors’ contributions
Conceived and designed the experiments: H Ali, Performed the experiments: A Ahmad, Analyzed the data: R Ahmad, Contributed materials/ analysis/ tools: H Ali & S Hussain, Wrote the paper: S Hussain & A Ahmad.

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