Journal of Pure and Applied Agriculture (2023) 8(3): 34-41
ISSN (Print) 2617-8672, ISSN (Online) 2617-8680
http://jpaa.aiou.edu.pk/

Optimizing cotton productivity: A comprehensive analysis of categorizing factor levels

Abdul Hameed[1], Muhammad Islam[1]*, Abdul Qayyum[2], Rabia Siddiqui[1] and Umar Draz[3]

[1]Deputy Director (Stat), Crop Reporting Service, Agriculture Department, Punjab, Pakistan
[2]Director General, Crop Reporting Service, Agriculture Department, Punjab, Pakistan
[3]Assistant Director (Stat), Crop Reporting Service, Agriculture Department, Punjab, Pakistan

*****Corresponding author: Muhammad Islam (mislam6667@gmail.com)

Abstract

Cotton crop termed as a white gold of Pakistan due to its immense importance for foreign exchange. Across the years, production of cotton is critically decreasing in Pakistan. In this study, efforts are made to layout the variables of interest in sequential way to enhance the cotton productivity. The dataset of 12504 crop cut experiments is collected from Crop Reporting Service, Punjab comprise from 2018-2021. Yield gap analysis, probability share, and ANOVA are applied to measure the variables and its levels. The probability shares of the farmers who are getting the optimum productivity for best factors' levels are 13.78% for sowing time up to 2nd fortnight of April, 25.78% for 10 water/irrigations, 0.12% for 3 weedicides spray, 3.53% for 13-17 pesticides spray, 3.18% for DAP, 19.65% for urea and 75.15% for cotton varieties. New theory is constructed for the categorization of variable in term of probability share (%), yield gap, and optimum productivity and it identify that sowing time, weedicide spray, pest spray and DAP falls under major loss, while water/irrigation and urea fall under medium loss and cotton varieties falls under minor loss. The productivity of cotton could be enhanced from major to minor loss factors, but in diminishing order. Firstly, there is need to address major loss factor, and then on medium and minor factors to get over the loss in cotton productivity. Mean differences for the group of all variables found statistically significant. This study is helpful for making strong recommendations to farmers liable to enhance the cotton productivity and could be viewed as an unprecedented effort for the sweet homeland, Pakistan. This study may also lead a basis to build the good regression model for cotton yield enhancement practices.

Keywords: Categorizations of factors levels, Cotton crop, Enhancement techniques, Productivity, Statistical analysis

To cite this article: Hameed, A., Islam, M., Qayyum, A., Siddiqui, R., & Draz, U. (2023). Optimizing cotton productivity: A comprehensive analysis of categorizing factor levels. *Journal of Pure and Applied Agriculture, 8*(3), 34-41.

Introduction

Significance of cotton crop for Pakistan

Cotton is a leading cash crop of Pakistan and also known as "a game change crop or a white gold of Pakistan" (Dahri et al., 2023; Kolachi et al., 2021; Nazeer et al., 2023). Pakistan stands at 4th largest producer of cotton crop in the world (Rehman et al., 2015). Cotton crop contributed about 0.6% to GDP, 2.4% of the value added in agriculture and export of cotton and textile products were contributing about 60% percent in overall exports of Pakistan (Afzal et al., 2023; Iqbal et al., 2023). Around two third of the country's export was earnings from the cotton. Hundreds of ginning factories and textile mills in the country are heavily depending on cotton crop production. Life of several farmers is also dependent on cotton crop, in addition to millions of people employed in the entire cotton value chain, from weaving to textile and garment exports.

According to economic survey of Pakistan 2022-2023, the area under cotton crop was 2.373 (millions) hectors for the year 2018-2019, 2.517 (millions) hectors for 2019-2020, 2.079 (millions) hectors for 2020-2021, 1.937 (millions) hectors for 2021-2022 and 2.144 (millions) hectors for 2022-2023. The area under cotton crop was decreased about 17.4% for the year 2020-21, 6.8% for 2021-2022, while increased about 10.7.% for 2022-2023. The productivity of cotton crop was found 707 kg/hectors for the year 2018-2019, 618 kg/hectors for 2019-2020, 578 kg/hectors for 2020-2021, 731 kg/hectors for 2021-2022 and 390 kg/hectors for 2022-2023. The productivity decreased about 12.6% for 2019-2020, 6.5% for 2020-2021, increased 26.5% for 2021-2022 and decreased about 46.6% for 2022-2023. Similarly, the production found 9.861(millions) bales for 2018-2019, 9.148 (millions) bales for 2019-2020, 7.064 (millions) bales for 2020-2021, 8.329 (millions) bales for 2021-2022 and 4.910 (millions) bales for 2022-2023. The production decreased about 7.2% for 2019-2020, 22.8% for 2020-2021 and increased about 17.9% for 2021-2022, while decreased about 41.0% for the year 2022-23. The area, productivity and production of cotton crop are consistently decreasing in Pakistan. The cotton productivity is drastically decreased for the year 2022-23 due climate change and disease attacks (Marral et al., 2023).

Arshad et al. (2019) studied the cotton crop using the descriptive statistical analysis in term of Punjab Agriculture Extension Wing Pakistan (PAEWP) for the promotion of cotton cultivation and they reported that the farmers who were using the recommended levels of inputs are getting the best yield in Punjab. Ahmad and Afzal (2019) studied the cotton productivity in term of credit contribution and they reported that technical inefficiency of farmers is one of the major reasons for the productivity loss in Pakistan and Pakistan getting lower yield than its potential level of cotton crop. Any decline in cotton productivity resulted adverse hit for the economy of Pakistan as Pakistan's export of cotton and textile products are contributing about 60% percent in overall exports of Pakistan economy. Pakistan ranks 4th in terms of cotton cultivations while it ranks on 39th in cotton productivity in the world (Rana et al., 2020). Pakistan annually imports about 1.5 to 2.00 million of cotton bales to meet their growing demand of local textile mills. Therefore, it has become a vital for Pakistan to increase it's per acre productivity to meet the growing need of cotton, inside from country.

Objective of the study

Rapid economic growth is a tangible question for Pakistan without attaining sustainable growth for cotton productivity. The productivity of cotton crop is continuously decreasing across the year, resulted a tangible loss for the economy of Pakistan from several years. This is study is design to statistically elaborates yield gap analysis for the significant factors, liable to enhance the cotton productivity in Pakistan. New theory of categorization of variable level are introduced using the portability share, optimum yield, and yield gap analysis. The cotton productivity enhancement techniques leaded to uphold the economy of Pakistan, as major part of Pakistan' foreign remittance is earned from cotton crop. A statistical analysis is presented for the effects of various allied variables that influence the cotton production. The detailed statistical analysis is helpful to steer strong recommendations to farmers regarding different parameters liable to enhance the cotton crop production and could be viewed as an unprecedented effort for the sweet homeland, Pakistan. This study may also lead a basis to build the good regression model for cotton yield enhancement practices.

Materials and Methods

Study area

This study is conducted in Punjab, Pakistan. Cotton crop is grown in all provinces of Pakistan, but Punjab occupied a top position in term of area and production. According to area, Punjab is 2nd largest province of Pakistan and producing 80% of the total cotton produced of country followed by Sindh (Imran et al., 2019; Wei et al., 2020). About 65% of Pakistan's cotton is sown in Punjab province and rest is sown in Sindh, while the cotton grown on nominal area in KPK and Balochistan, (Javed et al., 2006; Rana et al., 2020).

Source of data

This study based on secondary cross-sectional dataset of 12504 crop cut experiments collected from Crop Reporting Service (CRS), Agriculture Department, Punjab, Pakistan for the year 2018 to 2022. About 0.40 million values have been fed up with SPSS (Statistical Package for the Social Sciences) and used in this study to predict the optimum level of output in response of various input levels. The CRS is government organization, own by the Government of Punjab and responsible for the area, yield and production estimates of crops, fruits and vegetables etc. (Islam, 2022; Islam & Shehzad, 2022; Qayyum & Pervaiz, 2013).

Identification of agronomical constrains

Table 1 shows the identification of the agronomical constraints (variables) and their levels applied in the current study. The productivity of cotton crop maunds (40 kg)/acre is taken as dependent variables.

Table 1 Identification of factors and their levels

Factors	Levels of factors
Sowing time of cotton crop	Sowing up to 31 March, sowing up to 15 April, sowing up to 30 April, sowing up to 15 May and sowing up to 31 May
No. of irrigations	3 or less water/irrigations to 14 & above water/irrigations
weedicides spray	No. of weedicides spray (0-4)
Pest spray	No. of pest spray (0-17)
Fertilizers DAP	0 Kg, 25 Kg, 50 Kg, 75 Kg, 100 Kg and 125 Kg
Fertilizers urea	0 Kg, 25 Kg, 50 Kg, 75 Kg, 100 Kg and 125 Kg and 150-175 Kg
Cotton varieties	BT-MNH-886, BT-FH-142, BT-IUB-2013, BT-BS-15, BT-SS-32, BT-Others and Non-BT

Descriptive statistical analysis is presented with tabulation and graphical presentation of factors with their levels.

Normality and descriptive statistical analysis

In applied statistics, the normality of data is pre-requisite demand for the statistical analysis and graphical presentation is best technique for the large dataset (Gujarati, 2022; Islam et al., 2021). For the current study the normality analysis is performed using the graphical presentation (histogram with normal curve and P-P plots). Descriptive statistical analysis is performed using average, absolute/relative dispersion, probability share and yield gap analysis etc.

Cotton yield gap analysis

The yield gap analysis is performed using the effect of different level of agronomical constrains. The absolute and relative yield gap analysis is used to assess the yield gap of cotton productivity loss respectively in Mds/Acre and in relative term.

absolute $\bar{Y}_{C(i)gap} = \bar{Y}_{C(i)optm} - \bar{Y}_{C(i)avg}$ (1)

Relative $\bar{Y}_{C(i)gap} = [(\bar{Y}_{C(i)optm} - \bar{Y}_{C(i)avg})/\, \bar{Y}_{C(i)optm}] * 100$ (2)

Where *"i"* stands for the individual level of the *"i^{th}"* inputs factor, "$\bar{Y}_C$" stand the average yield of cotton

Mds/Acre, "$optm$" stands for the optimum/maximum average yield of cotton for the use of "i^{th}" inputs level at which yield is maximum, "avg" stand the average yield of cotton at "i^{th}" inputs levels other than maximum level.

Construction theory of variables categorization

The effect of different variables level is studied in the current research. At some level of inputs, the cotton productivity found optimum, while rest of the inputs level decreases the productivity on some or more extend. However, the probability share (%) of the farmers using different level of inputs also various from one level to another level. New theory is introduced here for the categorization of variables in term of yield gap analysis, probability share (%) and optimum productivity. This will help to raise the awareness of farmers, that how much productivity are losing, and which factors' level is soul responsible for productivity change. The following criterion is used to determine the categorization of inputs levels.

- The major loss variables are those, whose share (%) at optimum level of inputs falls within 15%. It means the rest share (%) of the farmers is losing the productivity at some or more extend.
- The medium loss variables are those, whose share (%) at optimum level of inputs falls within (15.1-50) %. It means the rest share (%) of the farmers is losing the productivity at some or more extend.
- The minor loss variables are those whose, share (%) at optimum level of inputs falls within (50.1 & above) %. It means the rest share (%) of the farmers is losing the productivity at some or more extend.

Analysis of variance (ANOVA) for the significance of mean difference

Analysis of variance (ANOVA) is a statistical analysis approach used to compare and to determine the significance differences in the datasets. The coefficient known as F-Statistic is applied in the ANOVA to determine, whether the statistically significant difference exist between the groups (levels) of variables of interest. F- Statistic used in ANOVA to determine the difference between the mean groups.

$$\text{F} - \text{Statistic} = \frac{\text{mean squares between groups}}{\text{mean squares of errors}} = \frac{\sum_{i=1}^{k} n_i(\bar{Y}_{i.}-\bar{Y})^2/(k-1)}{\sum_{i=1}^{k}\sum_{j=1}^{ni}(Y_{ij}-\bar{Y}_{i.})^2/(n-k)} \quad (3)$$

Where "$\bar{Y}_{i.}$" stands the means in the "i^{th}" groups, "n_i" stands the no. of observation in the "i^{th}" group, "$\bar{Y}$" stands the overall mean of the dataset, "k" stands the no. of groups, "Y_{ij}" is the "j^{th}" observations in the "i^{th}" out of "k" group and "n" is the total sample size. The hypothesis test for the significance differences between the groups (levels) means narrated as.

H_0: No significant difference between the means of variables groups being measured.

H_1 Significant difference between the means (at least two) of variables groups being measured.

Results and Discussions

Normality analysis

According to central limit theorem, for sufficiently large samples size, the distribution follows to approximately normally distribution (Gujarati, 2022). Figure 1 and Figure 2 shows the normality analysis for the cotton crop productivity using the histogram with normal curve and P-P plot. The graphical presentation indicates that the current dataset follows a normal distribution, suggesting no abnormalities found in the response variable (cotton productivity) within the dataset.

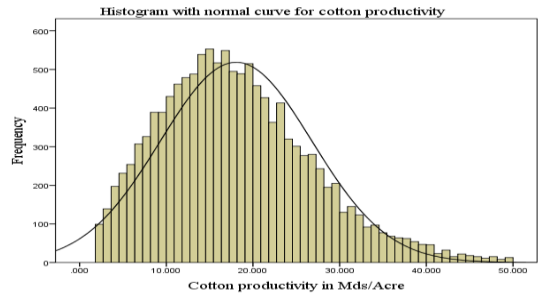

Fig. 1 Histogram with normal curve for cotton productivity

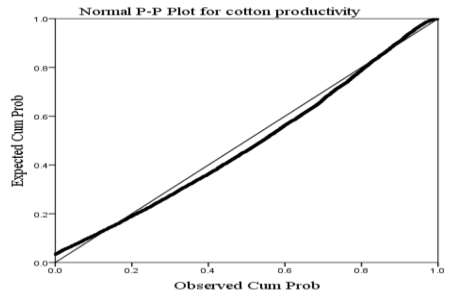

Fig. 2 P-P Plot for cotton productivity

Impact of sowing time on cotton productivity (yield)

Table 2 shows the disparity for the average gain of cotton productivity against its sowing period. In Pakistan, the sowing of early cotton is started from the month of March, but it is reported on nominal area of 4.92%. The mostly cotton crop is sown in the month of May on significant area 86.22% after harvesting the wheat crop. The cotton crop produced better results for the sow of March and April, but it is not feasible to sow significant area of cotton up to first fortnight of April as the area is occupied by wheat crop. Despite the clear benefits of sowing cotton up to second fortnight of April, only 13.78% of farmers are currently adopting this practice. Cotton crop is very sensitive for its sowing period. Sowing period is one of the crucial factors to attain the good productivity of cotton crop. It is observed that in Pakistan, early cotton sowing commences in the month of March but is practiced on nominal area of 4.92% of the total cotton-growing area. Bilal et al. (2019) emphasized the critical importance of selecting the appropriate sowing period of cotton crop for enhancing its productivity. In a similar vein, Ahmad et al.

(2018) reported that sowing cotton during March could lead to a remarkable increase of approximately 34.8% in productivity, compared to sowing in May. Our current study corroborates these findings with a slight variation, indicating that cotton crop productivity increased by approximately 23.6% and 29.13% when sown in March, against 1st and 2nd fortnights of May. It is intensely supporting the recommendation that cotton should be sown up to second fortnight of April, immediately after the harvest of wheat crop, so that, the gap between wheat harvest and cotton sowing will be optimized to achieve the best possible yields of cotton crop.

Table 2 Variations in cotton productivity in response of sowing period

Sowing time of cotton crop	Share (%)	Avg. yield maund/Acre
Sowing up to 31 March	4.92	22.25
Sowing up to 15 April	3.27	21.22
Sowing up to 30 April	5.59	19.75
Sowing up to 15 May	40.59	17.99
Sowing up to 31 May	45.63	17.23

Impact of number of irrigations on cotton yield

Table 3 shows the statistics for the variation in cotton productivity in response of different level of water/irrigations. It is observed that the cotton productivity is increasing by increasing the number of water/irrigations up to 10, but after 10 water/irrigations, the cotton productivity is then decreasing. The cotton crop produced optimum yield for its best level of 10 water/irrigations is 19.05 Mds/Acre. About 25.78% farmers applying the optimum level of irrigations and getting optimum yield, while the rest are not applying its optimum level and losing the productivity of 29.16% (5.55 Mds/Acre) for less than 3 water/irrigations, 27.08% (5.16 Mds/Acre) for four water/irrigations and this yield loss in decreasing and reaching to 7.06% (1.35 Mds/Acre) for nine water/irrigations. After the optimum gain at 10 water/irrigations the yield loss is then reported to rise again 6.48% for eleven irrigations, 7.74% for twelve and 5.58% for thirteen water/irrigations. Standard deviation shows that the variation found consistent and in nominal rang for all the water levels. Water/Irrigations are productive constrains to attain good productivity of cotton crop, but on which level of water/irrigations, the cotton crop got optimum productivity is tangible sign for the farmers of interest in Pakistan. Sahito et al. (2015) found that irrigating the cotton crop 6 times at 21-day intervals, resulted in favorable productivity. Additionally, Naheed & Rasul (2010) emphasized that the water requirements for cotton crops are influenced by climate change, with hotter days necessitating increased irrigation. This study demonstrated the irrigations up 14 water/irrigations and findings of this study indicate a clear trend that as the number of water/irrigations increases, cotton productivity also raises up to 10 water /irrigations. Farmers, who deviate from this optimal level, lead to a decline in cotton productivity.

Table 3 Variations in cotton productivity in response of water/irrigations

No. of irrigations	Share (%)	Avg.yield Mds/Acre	Absolute yield gap (loss)	Relative yield gap (loss)	Std. Deviation
3 or less	0.64	13.10	5.55	29.16	9.63
4	1.34	13.89	5.16	27.08	8.26
5	3.74	15.56	3.49	18.30	8.56
6	5.74	16.71	2.34	12.30	8.13
7	5.74	16.66	2.39	12.54	8.33
8	7.52	17.56	1.49	7.82	8.44
9	4.53	17.70	1.35	7.06	8.30
10	25.78	19.05	0.00	0.00	8.97
11	3.72	17.82	1.23	6.48	8.73
12	7.77	17.58	1.47	7.74	7.81
13	7.08	17.99	1.06	5.58	8.52
14 & above	26.40	18.76	0.29	1.51	8.99

Impact of weedicides spray on cotton productivity

Table 4 shows the comparison of cotton productivity by varying the number of weedicides spray operation. The cotton productivity found at optimum level for the three weedicides. It is verdict that only 0.12% farmers are applying the optimum level of weedicides spray operation in Punjab, while the maximum farmers (71.14%) are applying the one weedicides operation and getting the loss in productivity about 20.19%. it is further reported that 22.38% farmers are not applying any weedicides operation and reported 27.35% loss in cotton productivity. Standard deviation shows that the variation found consistent and in nominal rang for all the weedicides spray operations levels. Tanveer et al. (2003) reported that applications of optimized level of weedicides spray plays essential role to prevent the crop from weeds and to enhance the productivity. The study also evident that, achieving the optimum level of weedicide spray up to 3 weedicides sprays operations is pivotal for enhancing cotton productivity.

Table 4 Variations in cotton productivity in response of weedicides spray

weedicides spray	Share (%)	Avg.yield Mds/Acre	Absolute yield gap (loss)	Relative yield gap (loss)	Std. Deviation
0	22.38	16.62	6.25	27.35	8.49
1	71.14	18.25	4.62	20.19	8.72
2	6.29	20.84	2.03	8.87	9.02
3	0.12	22.87	0.00	0.00	7.59
4	0.07	20.46	2.41	10.55	5.06

Impact of pesticides spray on cotton productivity

Table 5 shows the characteristics of pesticides operation for the cotton productivity. It is revealed that maximum farmers are using 4-8 spray operation, while the optimum productivity found for the 14-17 spray operation. About 0.10% are not applying the pesticides operation and getting the loss in cotton productivity about 12.67 Mds/Acre (55.83%). The standard deviation revealed the consistent range for all level of pesticides spray operation. Sarwar et al. (2016) noted that cotton crop is highly susceptible to insect, pests, and diseases, and it is necessary to control these disease attacks by using the different pesticides operations. Khan et al. (2015) reported that pesticides play a pivotal role in modern agricultural practices, having gained widespread global acceptance for their role in preventing or managing pests and diseases for cotton crop. This study confirms that increasing the frequency of pesticides spray operations, leads to improved yields. It is commonly observed that higher spray frequency is associated with higher yield. Furthermore, any increase in the number of sprays results in higher the expenses. Farmers are advised to carefully analyze the cost-benefit analysis to optimize cotton productivity while managing pesticide-related costs effectively. Striking the right balance between productivity enhancement and cost control will ultimately lead to sustainable and profitable cotton farming practices.

Table 5 Characteristics of pesticides operation for the cotton productivity

Pest Spray	Share (%)	Avg.yield Mds/Acre	Absolute yield gap (loss)	Relative yield gap (loss)	Std. Deviation
0	0.10	10.03	12.67	55.83	7.35
1	0.55	11.43	11.27	49.66	8.65
2	2.58	13.26	9.44	41.60	8.80
3	6.62	15.38	7.32	32.26	8.61
4	12.16	16.13	6.57	28.95	8.28
5	15.80	17.79	4.91	21.61	8.48
6	17.47	18.28	4.42	19.47	8.36
7	13.33	18.56	4.14	18.26	8.29
8	12.09	18.84	3.86	16.99	8.55
9	5.57	19.34	3.36	14.81	8.70
10	5.09	19.29	3.41	15.03	8.78
11	1.87	21.25	1.45	6.37	9.44
12	3.23	21.05	1.65	7.27	9.60
13-17	3.53	22.70	0.00	0.00	10.02

Impact of fertilizer DAP on cotton productivity

Table 6 shows the variation in cotton productivity in response of application of DAP. The comparison shows that maximum (76.39%) farmers applying the one bag (50 Kg/acre) DAP and getting the yield about 18.36 Mds/ Acre, while the optimum yield obtained for the used of 100 kg DAP. Only 3.18% farmers are applying the optimum level of DAP fertilizer. The loss in productivity is reported to 38.15%, 31.11%, 19.97%, 6.06% and 13.33% for the use of DAP, as no, 25 Kg, 50 kg, 75 kg and 125 kg. It is verdict here that productivity enhanced up to 2 bags of DAP. The standard deviation revealed the consistent range for all level of DAP. Fertilization is a key component to get the better productivity. Di-ammonium Phosphate (DAP) is popular fertilizer applied in Pakistan to increase the soil fertility and plants nutrition. One bag (50 Kg) DAP contains 46% Nitrogen (N) and 18% Phosphorus (P). Sub-optimal DAP application is widespread among farmers, leading to significant yield losses (Wakeel et al., 2022; Ahmad et al., 2021). It is imperative for farmers to consider the DAP application up to 2 bags to get maximum yield. Further outreach efforts are needed to encourage the farmers about the benefits of optimal DAP fertilization.

Table 6 Variation in cotton productivity in response of application of DAP

DAP	Share (%)	Avg.yield Mds/Acre	Absolute yield gap (loss)	Relative yield gap (loss)	Std. Deviation
0 Kg	12.33	14.19	8.75	38.15	8.42
25 Kg	3.28	15.80	7.14	31.11	7.36
50 Kg	76.39	18.36	4.58	19.97	8.53
75 Kg	4.61	21.55	1.39	6.06	8.87
100 Kg	3.18	22.94	0.00	0.00	9.89
125 Kg	0.20	19.88	3.06	13.33	10.85

Impact of fertilizer urea on cotton productivity

Table 7 shows the change in cotton productivity in response of urea fertilization. The comparison shows productivity found optimum for the use of urea 150-175 kg per acre (at least 3 bags). There are 19.65% farmers are reported to use the optimum level of urea fertilizations and getting the optimum productivity, while the rest are getting the loss in productivity. It is verdict here that 53.64% farmers are applying the 100 kg urea and getting the loss in productivity about 17.36% (3.77 Mds/Acre). Standard deviation revealed the consistent range for all the urea levels. In Pakistan, urea is widely used fertilizers due to its high nitrogen content of 46%. Non-optimal use of urea is leading to significant yield loss (Kumbhar et al., 2008; Dhaunroo et al., 2018). There is need to address the yield gap to farmers, resulted from non-optimal used of urea and to encourage the farmers to apply the optimal urea fertilization. This research confirms Khan et al. (2006) findings that using at least three bags of urea per acre results in optimal cotton crop productivity compared to other urea levels.

Table 7 Change in cotton productivity in response of urea fertilization

Urea	Share (%)	Avg.yield Mds/Acre	Absolute yield gap (loss)	Relative yield gap (loss)	Std. Deviation
0 Kg	1.30	15.13	6.58	30.31	9.81
25 Kg	0.36	14.67	7.04	32.42	9.22
50 Kg	13.99	14.94	6.77	31.18	8.51
75 Kg	7.71	16.54	5.17	23.81	8.15
100 Kg	53.64	17.94	3.77	17.36	8.40
125 Kg	3.35	19.25	2.46	11.33	8.88
150-175 (Kg)	19.65	21.71	0.00	0.00	8.78

Cotton varieties and change in productivity

Table 8 verdicts the productivity variations for different cotton varieties. BT-SS-32 performed better than other cotton varieties and there are only 16.59% farmers are using the BT-SS-32. It is evident here that about 75.15% farmers are using the cotton varieties as BT-MNH-886, BT-IUB-2013, BT-BS-15 and BT-SS-32 and getting the best yield with minimum variations. Various varieties of cotton are sown in the Punjab. Karar et al. (2020) and Muhammad et al. (2016) reported that the productivity of cotton may vary from varieties to varieties, and this study also reinforces the importance of policy initiatives aimed at promoting advanced and sustainable cotton cultivars in Pakistan.

Table 8 Change in cotton productivity for the use of different varieties

Cotton Varieties	Share (%)	Avg.yield Mds/Acre
BT-MNH-886	4.93	16.87
BT-FH-142	8.74	15.66
BT-IUB-2013	21.48	17.63
BT-BS-15	14.65	18.36
BT-SS-32	16.59	19.51
BT-Others	17.50	18.56
Non-BT	16.11	17.97

Construction of categorization of loss variables and mean differences

Table 9 shows the severity and categorization of loss variable levels along with measured of the significance means differences for the variables groups (levels). The probability share of the farmers, who are operating the cotton crop are at optimum level of factors' levels are 13.78% for sowing time (up to 2nd fortnight of April), 25.78% (10 water/irrigations), 0.12% (3 weedicides spray), 3.53% (13-17 pesticides spray) 3.18% (DAP 100 Kg/ Acre), 19.65% (Urea (125-150) kg /Acre) and for varieties as 75.15% (BT-MNH-886, BT-IUB-2013, BT-BS-15, BT-SS-32). The farmers who are not operating the cotton crop at their best level are getting the loss in productivity found 86.22% for sowing time, 74.22% for water/irrigations, 99.88% for weedicides spray, 96.47% for pest spray, 96.82% for DAP, 80.35% for urea and 24.85% for cotton varieties. The values of F- statistic shows the all the means differences between the groups of all variables found statistically significant. Construction of new theory of variable categorization identify that sowing time, weedicide spray, pest spray and DAP falls under major loss, while water/irrigation and urea fall under medium loss and cotton varieties falls under minor loss. The productivity of cotton could be enhanced by opting best levels of inputs levels rapidly for major loss factors, medium for medium loss factor and minor for minor loss factors, which shows that the cotton productivity could be enhanced from major to minor loss factors but in diminishing order. There is need to work immediately on major loss factor, and then on medium and minor in factors to get over the loss in cotton productivity.

Table 9 Categorization of loss variable levels along with ANOVA

Factors	Farmers share (%) using the Optimum Levels of factor	Share (%) for rest of the farmers who are using others than optimum level of factor	Categorization of factor level	F- Statistic using ANOVA
Sowing time	Up to 2nd fortnight of April (13.78%)	86.22%	Major loss factor level	69.84**
weedicides spray	3 weedicides spray (0.12%)	99.88%	Major loss factor level	41.93**
Pest Spray	13-17 pesticides spray (3.53%)	96.47%	Major loss factor level	32.81**
Fertilizers DAP	DAP 100 Kg/ Acre (3.18%)	96.82%	Major loss factor level	116.67**
Fertilizers urea	Urea (125-150) kg /Acre (19.65%)	80.35%	Medium loss factor level	92.88**
Water/Irrigations	10 Water/Irrigations (25.78%)	74.22%	Medium loss factor level	16.26**
Cotton varieties	BT-MNH-886, BT-IUB-2013, BT-BS-15, BT-SS-32 (75.15%)	24.85%	Minor loss factor level	28.18**

** Verdict that the means difference of the factor is highly significant

Conclusion

Pakistan stands at 4th largest producer of cotton crop in the world, but across the years, its economic growth is at risk due to declining the cotton production. Optimal use of factors levels can offer a solution to boost cotton productivity. This study provides statistical support using data from 2018-2021 to quantify the impact of various factors on cotton productivity and to identify optimal levels of factor levels through yield gap analysis. In the context of optimizing cotton productivity, the best choice of factors levels found optimal for sowing period up to second fortnight of April, for irrigation at 10 water/irrigations, for weedicides at three spray operation, for fertilizers DAP at 2 bags and for urea at least 3 bags. Sustainable cotton cultivars are another crucial factor for getting optimal yield. New theory is constructed for the categorization of variables in term of probability share (%), yield gap and optimum productivity. It identifies that sowing time, weedicide spray, pest spray and DAP falls under major loss, while water/irrigation and urea falls under medium loss and cotton varieties falls under minor loss. The cotton productivity could be enhanced from major to minor loss factors but in diminishing order. This study is helpful for making strong recommendations to farmers regarding different parameters liable to enhance the cotton crop production and could be viewed as an unprecedented effort for the sweet homeland, Pakistan. This study may also lead a basis to build the good regression model for cotton yield enhancement practices.

Acknowledgements: The authors would like to appreciate the strong data collection mechanisms and efforts of all the team of CRS which is considerable as a good asset for our sweet homeland Pakistan. No funding support is available.

Conflict of interest: The authors declared no conflict of interest.

References

Afzal, M., Saeed, S., Riaz, H., Ishtiaq, M., & Habib-ur-Rahman, M. (2023). A critical review of whitefly (*Bemisia tabaci* gennadius) cryptic species associated with the cotton leaf curl disease. *Journal of Innovative Sciences*, *9*(1), 24-43.

Ahmad, D., & Afzal, M. (2019). Analysis of agriculture credit contribution in cotton production of southern Punjab, Pakistan. *Sarhad Journal of Agriculture*, *35*(2), 392-399.

Ahmad, S., Huifang, W., Akhtar, S., Imran, S., Yousaf, H., Wang, C., & Akhtar, M. S. (2021). Impact assessment of better management practices of cotton: a sociological study of southern Punjab, *Pakistan Journal of Agricultural Sciences*, *58*(1), 291-300.

Ahmad, S., Iqbal, M., Muhammad, T., Mehmood, A., Ahmad, S., & Hasanuzzaman, M. (2018). Cotton productivity enhanced through transplanting and early sowing. *Acta Scientiarum. Biological Sciences*, *40*, 1-7.

Arshad, I., Khan, Z. A., Vallejera, C. A. E., & Shah, N. H. (2019). The role of Punjab agricultural extension services in promoting cotton cultivation: Case Study. *PSM Biological Research*, *4*(3), 100-107.

Bilal, A., Ahmad, A., Rasul, F., & Murtaza, G. (2019). Optimization of the sowing time for Bt cotton production in Punjab, Pakistan. *Pakistan Journal of Agricultural Sciences*, *56*(1), 95-100.

Dahri, G. N., Wang, J., Khanzadab, B., Soomro, A. S., Hingorjo, W. B., Mari, M. A., Talpur, B. A., Nangraj, G. M., Tabassum, S. (2023). Impact of training approaches to reduce knowledge and skills gap in cotton crop: A case study Taluka Sinjhoro, District Sanghar, Sindh. *Journal of Applied Research in Plant Sciences*, *4*(1), 502-511.

Dhaunroo, A. A., Khan, R. A., Wagan, T. A., & Nahiyoon, A. A. (2018). Effect of different fertilizer doses with different combinations on cotton growth and yield. *Journal of Natural Sciences Research*, *8*(17), 1-5.

Gujarati, D. N. (2022). *Basic econometrics*: McGraw-Hill Higher Education.

Imran, M. A., Ali, A., Ashfaq, M., Hassan, S., Culas, R., & Ma, C. (2019). Impact of climate smart agriculture (CSA) through sustainable irrigation management on resource use efficiency: A sustainable production alternative for cotton. *Land Use Policy*, *88*, 104113.

Iqbal, Z., Ullah, M., Chohan, S., Iqbal, J., Farooq, M., Sarwar, M., Khan, R., Latif, A., Nazar, M., Saleem, M., Majeed, T., Ahmad, M., & Bano, T. (2023). Evaluation of genetic variability for different fiber and yield related components in Cotton (*Gossypium Hirsutum* L.). *Biological and Clinical Sciences Research Journal*, *4*(1), 1-12.

Islam, M. (2022). Integrating statistical and machine learning techniques to predict wheat production in Pakistan (Doctoral dissertation). Department of Statistics, the Islamia University of Bahawalpur, Punjab, Pakistan.

Islam, M., & Shehzad, F. (2022). A prediction model optimization critiques through centroid clustering by reducing the sample size, integrating statistical and machine learning techniques for wheat productivity. *Scientifica*, *11*, 7271293, doi: 10.1155/2022/7271293

Islam, M., Shehzad, F., & Omar, M. (2021). Modeling wheat productivity using hierarchical regression: A way to address food security concerns. *Elementary Education Online*, *20*(2), 1184-1195.

Javed, M. S., Hassan, S., Adil, S. A., Ghafoor, A., Bakhsh, K., & Siddique, A. (2006). Comparative advantage of cotton production and its policy implications in Pakistan. *Pakistan Journal of Agricultural Sciences*, *43*, 193-196.

Karar, H., Bashir, M. A., Haider, M., Haider, N., Khan, K. A., Ghramh, H. A., Ansari, M. J., Mutlu, C., & Alghanem, S. M. (2020). Pest susceptibility, yield and fiber traits of transgenic cotton cultivars in Multan, Pakistan. *PloS One*, *15*(7), 1-15.

Khan, A. A., Chaudhry, M. S., & Rashid, M. (2006). Farmers's attitude towards the use of agrochemicals for cotton crop: A case study of Lodhran district. *Pakistan Geographical Review*, *61*(1), 37-47.

Khan, M., Mahmood, H. Z., & Damalas, C. A. (2015). Pesticide use and risk perceptions among farmers in the cotton belt of Punjab, *Pakistan. Crop Protection*, *67*, 184-190.

Kolachi, M. M., Nahiyoon, A. A., Sehto, G. N., & Zaman, B. (2021). Effect of different doses of compost on growth and yield of cotton: Effect of doses on cotton growth. *Biological Sciences- Pakistan Journal of Scientific and Industrial Research, 64*(3), 283-287.

Kumbhar, A. M., Buriro, U. A., Junejo, S., Oad, F. C., Jamro, G. H., Kumbhar, B. A., & Kumbhar, S. A. (2008). Impact of different nitrogen levels on cotton growth, yield and N-uptake planted in legume rotation. *Pakistan Journal of Botany*, *40*(2), 767-778.

Marral, M. W. R., Ahmad, F., Ul-Allah, S., Atique-ur-Rehman., Farooq, S., & Hussain, M. (2023). Influence of transgenic (Bt) cotton on the productivity of various cotton-based cropping systems in Pakistan. *Agriculture, 13*(2), 1-15.

Muhammad, H. U. R., Ashfaq, A., Aftab, W., Manzoor, H., Javaid, A., & Hoogenboom, G. (2016). Estimation of temporal variation resilience in cotton varieties using statistical models. *Pakistan Journal of Agricultural Sciences, 53*(4), 787-807.

Naheed, G., & Rasul, G. (2010). Recent water requirement of cotton crop in Pakistan. *Pakistan Journal of Meteorology*, *6*(12), 75-84.

Nazeer, W., Zia, Z. U., Qadir, M., Ahmad, S., & Shahid, M. R. (2023). *Sustainable cotton production in Punjab: Failure and its mitigating strategies. Sustainable agriculture in the era of the OMICs revolution* (pp. 483-500), Springer.

Qayyum, A., & Pervaiz, M. K. (2013). A detailed descriptive study of all the wheat production parameters in Punjab, Pakistan. *African Journal of Agricultural Research*, *8*(31), 4209-4230.

Rana, A. W., Ejaz, A., & Shikoh, S. H. (2020). *Cotton crop: A situational analysis of Pakistan*. International Food Policy Research Institute

Rehman, A., Jingdong, L., Shahzad, B., Chandio, A. A., Hussain, I., Nabi, G., & Iqbal, M. S. (2015). Economic perspectives of major field crops of Pakistan: An empirical study. *Pacific Science Review B: Humanities and Social Sciences, 1*(3), 145-158.

Sahito, A., Baloch, Z. A., Mahar, A., Otho, S. A., Kalhoro, S. A., Ali, A., Kalhoro, F. A., Soomro, R. N., & Ali, F. (2015). Effect of water stress on the growth and yield of cotton crop (*Gossypium hirsutum* L.). *American Journal of Plant Sciences, 6*, 1027-1039.

Sarwar, M., & Sattar, M. (2016). An analysis of comparative efficacies of various insecticides on the densities of important insect pests and the natural enemies of cotton, *Gossypium hirsutum* L. *Pakistan Journal of Zoology*, *48*(1), 131-136.

Tanveer, A., Chaudhry, N. H., Ayub, M., & Ahmad, R. (2003). Effect of cultural and chemical weed control methods on weed population and yield of cotton. *Pakistan Journal of Botany*, *35*(2), 161-166.

Wakeel, A., Kiran, A., Shahid, M. R., Bano, Z., & Zia, M. H. (2022). Trends in nitrogen use and development in Pakistan. In Nitrogen Assessment (pp. 73-97). Academic Press.

Wei, W., Mushtaq, Z., Ikram, A., Faisal, M., Wan-Li, Z., & Ahmad, M. I. (2020). Estimating the economic viability of cotton growers in Punjab Province, Pakistan. *Sage Open*, *10*(2), 1-12.