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Nutrient requirements of non-basmati rice varieties in rice zone of Punjab, Pakistan

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Among various agronomic practices, the balanced use of fertilizers is important to get maximum economic yields. Therefore, this study was conducted to determine the economically optimum nutrient requirement for producing higher yields of non-Basmati varieties of rice. To achieve these objectives, experiments were conducted at 14 sites at farmers' fields from 2016 to 2020. The levels of nitrogen (N), phosphorus (P) and potash (K) were N (0, 87,174, 261), P_2O_5 (0, 52, 104, 156) and K_2O (0, 40, 80,120) kilogram per hectare respectively arranged in central treatment design with eleven treatments. Experiments were designed and conducted in the field under randomized complete block. Maximum paddy yield (6,223 kg ha) was obtained with 174-156-80 kg ha^{-1} on an overall basis. However, the maximum benefit cost ratio was observed with 174-0-80 kg ha^{-1} with a lower yield level. Marginal rate of return was higher for nutrient N due to its lower price but higher for P and K nutrients due to their higher prices. Based on the results, 174-156-80 kg ha^{-1} of N-P_2O_5-K_2O may be used by farmers seeking maximum incomes whereas 174-104-0 may be used by farmers seeking maximum cost benefit ratio, however, total income of farmers in this case may be lower.
Keywords: Nutrients, economics, rice, non-basmati, fertilizer, NPK, paddy yield.

INTRODUCTION

In Pakistan, rice is very important kharif crop and occupies the second position after wheat. Rice (Oryza sativa L) is very important food cereal in the world. Pakistan is at 10th place globally in production of rice. Pakistan's exports comprise about 8% of total world rice trade (USDA, 2018). In the year of 2021-22, Pakistan produced about 9.32 million tons of rice out of which 66% belonged to non-basmati varieties (GOP, 2022). In Punjab, during 2021-22, 31% of total rice area was under non-basmati varieties (CRS, 2022). Average yield of Rice in Pakistan is 3.6 t ha^{-1} with 4.1 and 7.1 t ha^{-1} in India and China respectively (USDA 2023) which shows a large potential for yield maximization. Maximization of rice yields can only be achieved with balanced use of nutrients especially for macro fertilizer nutrients of nitrogen (N), potassium (K) and phosphorus (P) and in optimum quantities. Nitrogen applied to rice plants is responsible mainly for vegetative growth, photosynthesis and also contributes towards grain filling through translocation during re-productive phase (Swain and Jagtap, 2010). Nitrogen also contributes actively towards accumulation of carbohydrate in culm and leaf sheaths before heading stage (Ganga Devi *et al.,* 2012). Prosper (2017) reported that yield of rice was increased by 19-41% as a result of fertilization and ranked as NPK > NP >NK > PK and showing that deficiency of N was main limiting factor for higher paddy yields. The highest and the lowest N, P and K accumulation was observed under N+P+K and P+K fertilization respectively. Sharma *et al.* (2017) also reported that among different yield limiting factors in rice, one is the sub-optimal use of nitrogenous fertilizers. An increase in nitrogen application has been reported to increase other nutrient contents in other plant species also like a study on jujube reported by Hegab *et al.* (2021). A work reported by Younis *et al.* (2021) on lettuce where an increase in N dose led to increased contents of K, N, Ca and Mg in plant tissues but increased P application level led to increase in plant P content only. However, as reported by Mian *et al.* (2021), the application of nitrogen may improve uptake of other nutrients only upto a certain level of soil application which was 75 kg ha^{-1}in his study to increase the NPK uptake by maize grains but beyond that level, no

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further increase in uptake was observed. Yousaf *et al.* (2017) also reported that an increase in N supply increased the plant height, dry matter yield; and N, P, K and Ca in grain. Masni and Wasli (2019) reported highest uptake of N with application of 180, 105 and 120 kg of N, P_2O_5 and K_2O per hectare. He attributed low N uptake without N application to very low indigenous soil N supply. Nitrogen uptake gradually increased when the dose of applied N was increased.

Phosphorus is an important building block of nucleic acids. It also improves the quality of produce and helps in improving availability of other nutrients; however, the deficiency of phosphorus (P) results in reduction of per plant number of tillers and the plant height. (Nawaz, 2002, Islam *et al.* 2015). P fertilizer application increased the rice yield components, in the study reported by Massawe and Mrema (2018), when the levels of P application was increased from 0 to 60 kg P_2O_5 ha^{-1} for all sources. This increase was attributed to increased phosphorus availability and uptake of nutrients especially P. Residual soil N and P has significantly been affected by P fertilizers and application rates as well as when the level of P was increased to 60 kg P ha^{-1}.

Potassium (K) fertilizer affects the growth and final yield of rice. Govhane (2001) applied K at different rates as (0 to 80 kg ha^{-1}) which increased the yield components like plant height, length of panicle, at maturity production of dry matter, grain and straw yields. However, spikelet panicle, grains filled in a panicle, at panicle initiation dry matter yield (PI) stage increased linearly. Similarly, (Mae, 1997) also showed better response by rice to potassium by cereals, millets because K improves respiration of roots plus tillering in submerged condition. Uptake of 'K' is more than any other nutrient and low potash in soil increases the response to applied potassium in rice. Similar information about the response of nutrients is available for other parts of the world. However, little data is available on nutrient requirement of non-basmati varieties of rice in rice zone of Punjab Pakistan. Therefore, this field study was carried out to quantify response of non-basmati varieties of rice to soil application of nutrients and its economics in rice zone of Punjab.

MATERIALS AND METHODS

***Sites*:** The study was conducted at farmers' fields from 2016 to 2020 at 14 sites situated in Gujranwala and Lahore Divisions in Punjab province in Pakistan which is a core area for paddy production. Non-Basmati varieties were used in this study which included PK-386 (11 sites) and PK-1121 (3 sites).

***Climate*:** Climate plays a very important role in growing of rice crop especially rainfall and temperature. Lahore and Gujranwala division are geographically contiguous in north of Punjab Province (Fig.1). Gujranwala divisions have a hot semi-arid climate according to the Köppen-Geiger system. During summers, June to September reach to a maximum monthly temperatures of 35 to 40.8 ºC. However, November to January is relatively cool with minimum monthly temperatures reaching low to 5.3 to 10.3 ºC. Maximum rainfall months are July and August with 147 and 168 mm of rainfall which is 54 percent of total annual rainfall. Weather of Lahore is also almost similar to that of Gujranwala and it has a semi-arid climate with June to September maximum temperatures ranging between 35 to 40.4 ºC (https://en.climate-data.org/). The average rainfalls during July and August are 202 and 164 mm respectively. In both these divisions, rainfalls received during these two months play an important role in growing non-basmati varieties of rice whose transplanting starts in end of June.

Figure 1. Map of Pakistan and Punjab Province (Study area).

***Soil characteristics*:** Major soil orders prevalent in rice zone are Vertisols, Alfisols and Aridisol. Lahore, Sheikhupura, Gujranwala, Sialkot, Narowal and Hafizabad are major districts in rice zone. Soils of rice zone comprise of mixed calcareous alluvium. These are generally silty clays having poor drainage and heavy in texture. Therefore, percolation of rainfall and applied water is relatively slow. Dominant soil series in these divisions include Bhalwal, Hafizabad, Lyallpur and Sialkot, Eimenabad, Gujranwala and Khurrianwala series (SSP 1968.). Rice-wheat cropping rotation is major rotation in this zone.

The soils of experimental sites were alkaline in nature (Table 2). However, the sites were found free of salinity and sodicity having ECe and pH less than 4.0 dS m^{-1} and 8.5 respectively. The organic matter contents in soils were found low to medium with average contents varying from 0.63 to 0.94%. Average available phosphorus in soils was low (less than 7.0 mg kg^{-1}) with few sites above it. Potash contents of these soils were medium (between 80 and 180 ppm) on average during all years except 2018 where these were adequate (>180 mg kg^{-1}) according to the classification by Malik *et al.* (1984).

***Soil analysis*:** Soil samples were taken from all the fields from 0-15 and 15-30 cm depths. The samples were brought to the lab for analysis. These were air-dried followed by sieving with a 2 mm sieve. The samples were analyzed for electrical conductivity and pH according to the methods described in Handbook 60 (Richard, 1954). Soil organic matter was analyzed according to the method described by Walkley and Black method (1934) mentioned in Nelson and Sommers (1982). Available phosphorus in soil was extracted through 0.5M sodium carbonate solution and color development by ammonium molybdate method described by Olsen and Sommers (1982). Available potash in soil was extracted through 1N ammonium acetate and read with a flamephotometer. Canal water was used to irrigate the crop which was supplemented with tubewell water.

***Study design*:** There were four levels of nitrogen, four of phosphorus and four of K in this design. Details of treatments are given in Table 1.

Table 1. Treatment detail of experiment.

Tr. No.	Nutrients (kg ha^{-1})		
	N	P_2O_5	K_2O
1	0	0	0
2	0	104	80
3	87	104	80
4	174	104	80
5	261	104	80
6	174	0	80
7	174	52	80
8	174	156	80
9	174	104	0
10	174	104	40
11	174	104	120

***Treatment details*:** There were eleven treatments (Table 1) consisting of a central treatment of T_4. The layout at all sites was randomized with three replicates. Treatment or subplot size was about 1/40th of a hectare at all sites According to treatment table, half of nitrogen was applied one week after transplanting and the remaining half N at 30-35 days after transplanting. All phosphorus, potash and zinc were applied to the soil through broadcast one week after transplanting. Zinc was applied to all treatments @ 5 kilograms of zinc per hectare in the form of zinc sulfate.

***Other field operations*:** The rice crop was grown in puddled fields (irrigated lowland rice). Canal and tub well water, whichever is available was used every second or third day to maintain the level of water standing in the field for growing rice. Seedlings were grown in separate fields and transplanted in the field at all these sites mostly from the end of June to mid-July. The crop was harvested mostly in mid-October. All other practices of insect and disease control were done as and when needed according to experts' recommendations at individual sites.

***Yield data collection*:** Subplots were harvested from all experimental plots. The bundles were dried for almost one day and then shredded through beating and the paddy yield data was collected.

Statistical analysis: Yield data was pooled over years and analysis of yield data was done using analysis of variance technique described by Gomez and Gomez (1984) after pooling the data of all years.

***Economical analysis*:** Economics of individual N, P, and K fertilizers was done application, benefit-cost analysis and marginal rate of return techniques were used. Here benefit-cost analysis was calculated as:

Benefit-cost ratio = Value of crop ÷ Fertilizer cost.

Whereas marginal rate of return (MRR) was calculated as:

MRR = Marginal revenue ÷ Marginal nutrient cost

Marginal revenue was the additional paddy yield above the previous level of fertilizer and the marginal nutrient cost was the additional cost of fertilizer above the previous level.

RESULTS AND DISCUSSION

***Effect of NPK on paddy yield*:** Soil application of N, P and K fertilizers increased paddy yield with increasing doses of these nutrients (Fig. 2a, 2b, 2c, 2d, 2e and 2f). On average, the application of N increased the yield up to 174 kg ha^{-1}. Beyond this level, the yield was not increased further as it is evident from T_5. These results were obtained during three out of four years. During 2017, the yield decreased with higher level of N (Fig. 3b). However, during 2019, the yield increased (Fig. 2d). Similar results were obtained by Manzoor *et al.* (2006)

Table 2. Pre sowing soil analysis of experimental sites.

Year	2016		2017		2018		2019		2020
# of sites	5		3		3		2		1
Soil parameters	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Value
ECe (dS m^{-1})	1.95	1.07-3.50	1.40	1.20-1.60	2.23	1.80-2.70	1.70	1.20-2.20	1.60
pH	7.9	7.6-8.3	8.1	7.9-8.3	8.0	7.8-8.4	7.9	7.8-8.0	8.1
O.M. (%)	0.94	0.67-1.42	0.74	0.51-1.04	0.66	0.50-0.77	0.71	0.50-0.92	0.63
Av P (mg kg^{-1})	5.7	2.7-9.6	7.0	4.3-9.5	5.0	3.0-7.0	6.4	2.5-10.3	5.1
Ex K (mg kg^{-1})	133	92-188	152	74-205	218	180-278	96	79-112	126

while working on the same soils. But the results of N response upto 175 kg ha^{-1} were on Basmati variety. The decrease in yield beyond certain levels of N is associated with the incidence of disease with higher N owing to disease or insect attack (Zaiyuan *et al.,* 2021; IRRI, 2022) or lodging of crops with higher doses (Castillejo *et al.,* 2010; Kaufman *et al.,* 2013, Zhang *et al.,* 2016). Therefore, N of 174 kgha^{-1} was the highest level of feasible application for non-basmati varieties of rice.

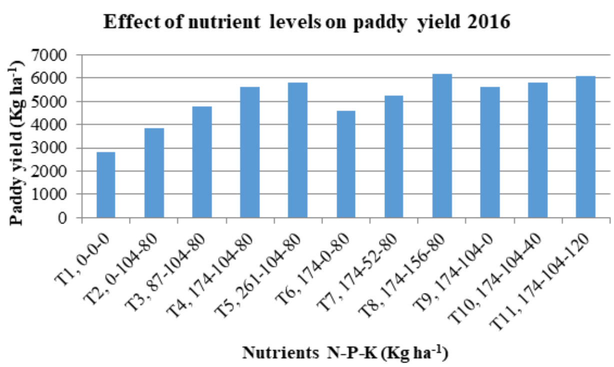

Figure 2a. Effect of N, P and K application levels on paddy yield (Non-Basmati) during 2016.

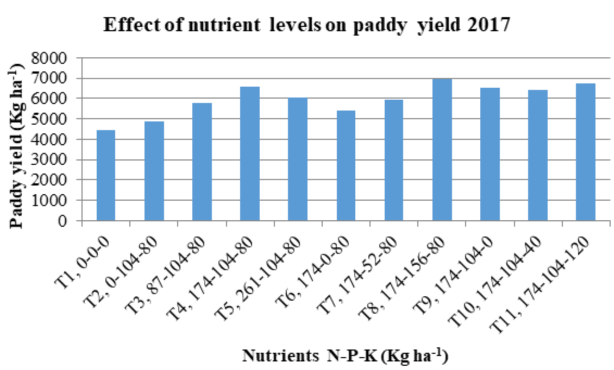

Figure 2b. Effect of N, P and K application levels on paddy yield (Non-Basmati) during 2017.

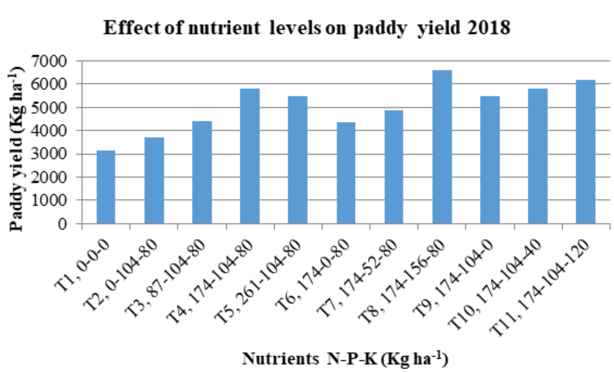

Figure 2c. Effect of N, P and K application levels on paddy yield (Non-Basmati) during 2018.

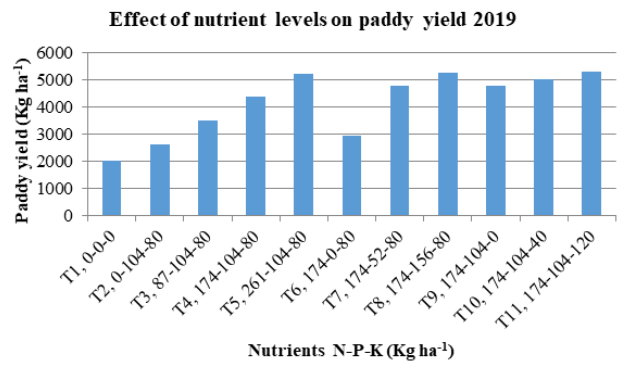

Figure 2d. Effect of N, P and K application levels on paddy yield (Non-Basmati) during 2019.

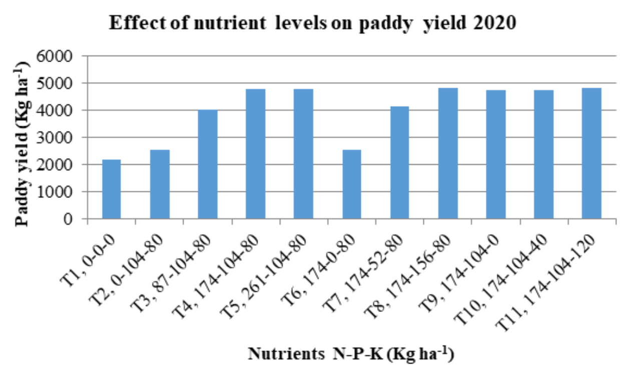

Figure 2e. Effect of N, P and K application levels on paddy yield (Non-Basmati) during 2020.

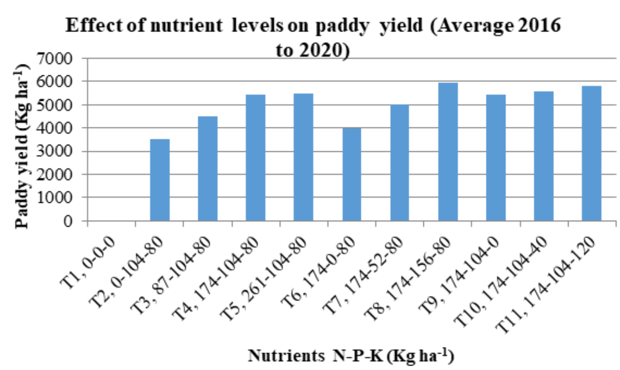

Figure 2f. Effect of N, P and K application levels on Mean yield of paddy during 2016 to 2020.

On an overall basis, with the application of phosphorus, the yield of paddy continued to increase upto 156 kg ha^{-1}. However, in 2017, the yield was not increased further beyond the application of 104 kg ha^{-1} of P. The reason could be the limitation of varietal yield potential beyond 6601 kg ha^{-1}. In 2020, paddy yield was not increased beyond the application of 104 kg ha^{-1} perhaps due to climatic factors.

On overall basis, the application of K did not increase the yield upto 80 kg ha^{-1}. However, it did increase yield at 120 kg ha^{-1}. The lack of response of potash with lower doses of K may be attributed to generally adequate levels of potash at experimental sites ((Fig. 2a, 2b, 2c, 2d, 2e and 2f)). The response of K at highest dose of 120 kg ha^{-1} may be due to lavish consumption of K or its interaction with some other nutrient like N.

During the study period, the experiments were done in a specific rice tract and the properties of these soils were not strikingly different from each other. Most of the soils were deficient and few medium in available phosphorus and organic matter. Therefore, all sites responded well to application of fertilizers during all the years. Hence, the main factor behind annual variation was the variation of weather, disease incidence etc. Maximum yields during the period of study were observed with T_8 (174-156-80 kg ha^{-1}). Out of these, maximum yield was observed during 2017 which was 6938 kg ha^{-1} whereas minimum yield in this treatment was observed during year 2020 which was 4749 kg ha^{-1}.

Economic analysis

***Benefit cost analysis*: ** Maximum benefit or income Rs 2,10,026 (Rs=Pak Rupee) was obtained with T_8 (174-156-80 kg ha^{-1}) which was followed by T_{11} with Rs 2,03,850 per hectare (Table 3). However, as far as benefit cost ratio is concerned, it was highest (3.12) in T_6 with 174-0-80 kg ha^{-1} of N-P_2O_5-K_2O with benefit (value of produce) of Rs 1,46,441 per hectare. It was followed by 174-104-0 kg ha^{-1} in T_9 with Rs 1,88,190 of income per hectare (BCR=2.68). Increasing productivity with increasing inputs has also been reported by Rahaman *et al.* (2022). Moreover, profitability depended on variety and season also. Fertilizer was one of the various

Table 3. Cost benefit analysis of combined fertilizer application for non-basmati rice.

Sr.	N	P_2O_5	K_2O	Fertilizer cost (Rs ha^{-1})	Paddy yield (t ha^{-1})	Value of paddy (Rs ha^{-1}) @ 33.75 kg^{-1}	Benefit cost ratio
1	0	0	0	0	3.070	1,03,613	-
2	0	104	80	71,008	3.771	1,27,271	1.79
3	87	104	80	82,544	4.658	1,57,208	1.90
4	174	104	80	94,080	5.646	1,90,553	2.03
5	261	104	80	1,05,616	5.610	1,89,338	1.79
6	174	0	80	47,000	4.339	1,46,441	3.12
7	174	52	80	70,540	5.147	1,73,711	2.46
8	174	156	80	1,17,620	6.223	2,10,026	1.79
9	174	104	0	70,152	5.576	1,88,190	2.68
10	174	104	40	82,116	5.741	1,93,759	2.36
11	174	104	120	1,06,044	6.040	2,03,850	1.92

Prices fertilizer per 50 kg bag: Urea = Rs 3,050, DAP= Rs 11,600, MOP= Rs 8,973: Paddy price = Rs 1,350 per 40 kg; hence nutrient prices are N=Rs 133, P_2O_5=Rs 453, K_2O=Rs 299 per kg; 1US$= Pak Rs 287.

Table 4. Rate of return of application of individual nutrients N, P and K on paddy yield.

Tr.	N	P_2O_5	K_2O	Fertilizer cost (Rs ha^{-1})	Paddy yield (t ha^{-1})	Marginal increase in yield (t ha^{-1})	Marginal cost (Rs ha^{-1})	Marginal revenue Rs ha^{-1} (@ Rs 33.75/ kg)	MRR
Nitrogen									
2	0	104	80	0	3.070	-	-	-	-
3	87	104	80	0	3.771	-	-	-	-
4	174	104	80	11,536	4.658	0.887	11,536	29,936	2.59
5	261	104	80	23,072	5.646	0.988	11,536	33,345	2.89
Phosphorus									
6	174	0	80	0	4.339	-	-	-	
7	174	52	80	23,540	5.147	0.808	23,540	27,270	1.16
4	174	104	80	47,081	5.646	0.499	23,540	16,841	0.72
8	174	156	80	70,621	6.223	0.577	23,540	19,474	0.83
Potash									
9	174	104	0	0	5.576	-	-	-	-
10	174	104	40	11,964	5.741	0.165	11,964	5,569	0.47
4	174	104	80	23,928	5.646	-0.095	11,964	-3206	-0.27
11	174	104	120	35,892	6.04	0.394	11,964	13,298	1.11

factors which affected the economics. However, according to law of diminishing returns, the profitability decreases after a certain level of input. The overall benefit cost ratio of rice production has a benefit cost ratio between 1.25 and 2.36 in study reported by Chanda *et al.* (2019). Moreover, in a study reported by Fahmid *et al.* (2022), the revenue cost ratio is 1.85 in Indonesia. However, in present study benefit cost ratio was between 1.79 and 3.12 which appears better than the two cases mentioned above.

Marginal Rate of Return**:** Marginal rate of return with N application was 2.59 or 2.89 which was relatively higher than P and K due to lower price of N (@ Rs 132.6 per kg. MRR was higher with 261 kg of N per hectare (Table 4). For phosphorous, MRR was highest (1.16) at 52 kg ha^{-1} and it decreased afterwards. It was lowest with 104 and 156 kg ha^{-1} (0.72 and 0.83) both treatments being statistically equal. MRR of P was lower than N due to its higher price of Rs 452.7 kg^{-1}. For K, application of lower levels upto 80 kg ha^{-1} was statistically non-significant with zero application. However, application of K @ 120 kg ha^{-1} had a MRR of 1.11. MRR greater than 1.0 may be considered profitable in evaluating profitability of inputs. However, due to higher P and K fertilizer prices, the P and K application was profitable with 52 and 120 kg ha^{-1} of P and K.

Conclusions**:** Application of NP and K in the soil increased the paddy yield. However, there was great difference in the profitability of nutrients due to their prices. Application of N was profitable in highest doses also but the negative effects of excessive N application need to be considered. The profitability of P and K was lowest due to higher prices. N, P and K gave highest rate of return with 174, 52, 120 kg ha^{-1} respectively. Therefore, these levels may be recommended for farmers seeking higher rates of return. For maximum yields, N, P and K of 174-156-80 kg ha^{-1} may be recommended for progressive farmers.

Authors contribution statement**:** Muhammad Nadeem Iqbal planned and supervised, Muhammad Shakir supervised, Fariha Amin reviewed, H. Riaz Ahmad and Samina Hamid conducted in field, Abdul Ghaffar and Asia Munir prepared the paper draft, Zia Chishti finalized the manuscript. Amir Hameed applied statistics and economics.

Conflict of Interest**:** The authors hereby declare no conflict of interest.

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Ethical statement**:** This article does not contain any study regarding human or animal.

Availability of data and material**:** We declare that the submitted manuscript is our work, which has not been published elsewhere before and is not being considered for publication elsewhere.

Code availability**:** Not applicable.

Consent to participate**:** All authors have participated in present research study.

Consent for publication**:** All authors submitted consent to publish this research article in JGIAS.

SDG's Addressed**:** Zero Hunger, Responsible Consumption and Production, Climate Action.

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