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Economically Optimal Rate of N-P-K Fertilizers of Fodder Maize for Central Punjab, Pakistan

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Abstract

Low inherent nitrogen (N), phosphorus (P), and potassium (K) soil concentrations are the major impediments to achieving realistic agronomic benefits in Central Punjab, Pakistan. Fodder is one of the cheapest sources of quality fodder but yet to have precise fertilizers recommendations. Therefore, exploring the optimum dose of N-P-K fertilizers for fodder maize is necessary to obtain the potential harvest. The present study was conducted on multiple farmers' lands in Central Punjab, Pakistan during 2015-2019. The treatments of fertilizers N, P_2O_5, and K_2O used in this study were 0–0–0 (control), 0–60–30, 65–60–30, 130–60–30, 195–60–30, 130–0–30, 130–30–30, 130–90–30, 130–60–0, 130–60–15, and 130–60–45 kg ha^{-1}. The experimental design in each field was a completely randomized block design with three replications. All P, K, and half of N were applied at sowing. The second half of N was applied at 0.75-meter plant height. The results showed that fresh maize fodder yield was increased as the levels of NPK were increased. Compared to the recommended dose (T_4) of N-P-K, the modified dose (T_8) of N-P-K increased the maize fodder yield by 8.02% with a better benefit-cost ratio and marginal rate of return. Similarly, on the basis of the benefit-cost ratio and net benefit, 195-60-30 and 130-90-30 kg ha^{-1} of N-P_2O_5-K_2O were found more beneficial. Therefore, these N-P-K doses can be recommended for farmers growing maize fodder in Central Punjab, Pakistan.

Keywords: Maize; Fodder; Economics; Fertilizer; Cost-Benefit Ratio

1. Introduction:

The share of livestock is 62% in agriculture and 14% in the GDP of Pakistan (GOP 2022). However, the shortage of fodder for livestock feed is one of the most limiting factors for livestock growth in Pakistan. Actually, the supply of fodder is one-third of its actual requirement while the area under fodder production has decreased during the last decade without any significant corresponding increase in per-hectare fodder production in Pakistan (Younas & Yaqoob, 2005). Therefore, it is imperative to increase fodder production to overcome the deficiency of livestock fodder. It has been reported that maize is the cheapest and most valuable source of animal feed being a rich source of nutrients, metabolizable energy, proteins, carbohydrates, and water. In Central Punjab, 80-90% of livestock nutrient requirements are met by fodder

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crops. Maize is a short-duration green fodder crop. It has an edge over other cultivated fodder crops due to high production potential, wider adaptability, quick growing nature, succulence, palatability, excellent fodder quality, and free from toxicants, and can safely be fed to animals at any stage of crop growth (Jamil *et al*., 2015).

However, in Pakistan, maize fodder yield per unit area is still very low as compared to other maize-growing countries despite the soil and climatic conditions of Pakistan suit well to maize fodder production. In this connection, it has been anticipated that appropriate and precise nutrients are one of the major factors limiting maize fodder yield. It is worth mentioning that almost all Pakistani soils are deficient in nitrogen (N) and phosphorus (P) while the status of potassium (K) is variable (Khan *et al*., 2021). We know that N promotes rapid vegetative growth and increases crop yields. Similarly, P plays a major role in photosynthesis and stimulates early growth and root formation. Amongst the essential plant nutrients, N and P are often the most important determinants of plant growth and crop yield. Adequate bioavailability of soil N and P has, therefore, the ability to increase maize fodder yield and quality by increasing the plant height, leaves, crude protein, and ash contents (Rafiullah *et al*., 2020). Most Pakistani soils are alkaline calcareous characterized by high soil pH, and deficiency of soil organic matter (SOM). Such soils are leading to severe N deficiency due to heavy N losses under such conditions (Raza *et al*., 2018). Similarly, P is fixed in these soils due to calcareousness and deficiency of soil organic carbon (SOC) (Jamal *et al*., 2018).

Maize (*Zea mays* L.) is ranked the 4^{th} most important crop in Pakistan after wheat, rice, and cotton. And not only in Pakistan but it has equal importance in other countries as a staple crop. It belongs to the group that has a high growth rate producing high biomass which in return demands high nutrient application (Mengel & Kirkby, 2001). Proper fertilization besides increasing fertilization efficiency, productivity, and farmers' income, can also affect the sustainability of the production system, environmental sustainability, and saving energy resources. To achieve high fertilization efficiency, it is necessary to pay attention to several things. They are (1) the type of plant/variety and nutrients required to achieve yield optimal; (2) nutrient availability in the soil; and (3) kinds of fertilizer as well as the right method and time of application (Suyamto, 2010). For the successful growing of maize fodder, nutrients should be applied in sufficient and balanced quantities. N, P, and K are major nutrients to sustain healthy crop growth and yield.

It has been observed during the last few years that the fodder yield of maize is either stagnant or declining in the study area which is attributed to inappropriate fertilizer use and recommendations. Realizing this research gap and the vast demand for fodder, in Central Punjab due high population of livestock, this study aimed to develop realistic fertilizer recommendations on the basis of field experimentation. The high-quality fodder can be produced through the balanced use of fertilizers. This implies the introduction of balanced and economical fertilizer recommendations by addressing the main constraints of conventional fertilization practices. The previous work on the response of maize to N, P, and K applications for fodder maize is either unavailable or not specific to the area under study. Therefore, this study has been conducted to ascertain the response of N, P, and K fertilizers on the yield of maize fodder and its economics.

1.1. Objectives:

- To investigate the optimal N-P-K rates for fodder maize.
- To find out the most economical N-P-K rates for fodder maize.

2. Materials and Methods:

2.1. Description of the Study Sites:

The study was conducted in 3 different locations of Central Punjab, Pakistan including Sargodha (Latitude: 31° 46' 59.99" N Longitude: 72° 16' 60.00" E), Faisalabad (Latitude: 31° 25' 7.3740'' N Longitude: 73° 4' 44.7924'' E), and Sahiwal (Latitude: 30° 39' 51.84" N Longitude: 73° 06' 29.88" E) during 2015-19. The climate of these areas is arid to semi-arid with average annual rainfall; Sargodha 440 mm, Faisalabad 101 mm, and Sahiwal 349 mm. All sites have well-established canals system for irrigation while the crops were supplemented with tube-well water during canal water shortages. The cultivation is commonly practiced at all experimental locations without any constraint.

Figure 1. Map showing the study area

2.2. Experimental Design and Field Operations:

The experiment was laid out following a randomized complete block design having 11 treatments (Table 1). In every treatment, only one nutrient varied, whereas the other two nutrients had recommended levels. The area under each treatment was ½0th of a hectare. Conventional non-hybrid variety of maize *Neelum* was planted keeping the line-to-line distance of 30 cm and plant-to-plant of 15 cm following a seed rate of 80 kg ha^{-1}. The sowing was done in the last week of May to the end of July and harvested in the last week of September to the first week of November, depending upon the harvestable crop in each location. All P_2O_5, K_2O, and ½ of N were applied at the time of sowing through broadcast while the remaining ½ N was applied through broadcast at 0.75 m plant height. During the growth period, appropriate field practices regarding irrigation, weeding, and plant protection measures were done as per requirement. Green fodder was harvested when the crop showed about 50% flowering. The biomass data were recorded and the yield data of fodder were taken by harvesting sub-sample of each plot

Table 1: N, P, and K doses applied to maize crop

Treatments	Nutrient (kg ha^{-1})		
	N	P_2O_5	K_2O
T_1	0	0	0
T_2	0	60	30
T_3	65	60	30
T_4	130*	60	30
T_5	195	60	30
T_6	130	0	30
T_7	130	30	30
T_8	130	90	30
T_9	130	60	0
T_{10}	130	60	15
T_{11}	130	60	45

*Recommended rate

2.3. Pre- Sowing Soil Analysis:

Soil samples (0-15) were collected from all farmer lands of the study area before the sowing of maize. These soil samples were brought to the laboratory, air-dried, and ground for chemical analysis including soil reaction (pH), electrical conductivity (EC_e), soil organic matter (SOM), available -P, and extractable -K. Soil pH and ECe were recorded after taking an extract from the soil-saturated paste and taking readings with Hanna instruments after standardizing with standards (Richards 1954). Soil organic matter was estimated following Walkley and Black method given by Nelson and Sommers (1996). Available P was measured after extracting the soil with 0.5 M $NHCO_3$ followed by color development with ammonium molybdate the Spectrophotometer was used to obtain reading at 880 nm wavelength (Olsen & Sommers, 1982). Extractable K was measured by extracting soil with 1 N ammonium acetate and the reading was taken by using Jenway Flame Photometer PFP-7.

2.4. Statistical and Economic Analysis:

Soil samples (0-15) were collected from all farmer lands of the study area before the sowing of maize. These soil samples were brought to the laboratory, air-dried, and ground for chemical analysis including soil reaction (pH), electrical conductivity (EC_e), soil organic matter (SOM), available -P, and extractable -K. Soil pH and ECe were recorded after taking an extract from the soil-saturated paste and taking readings with Hanna instruments after standardizing with standards (Richards 1954). Soil organic matter was estimated following Walkley and Black method given by Nelson & Sommers (1996). Available P was measured after extracting the soil with 0.5 M $NHCO_3$ followed by color development with ammonium molybdate the Spectrophotometer was used to obtain reading at 880 nm wavelength (Olsen & Sommers, 1982). Extractable K was measured by extracting soil with 1 N ammonium acetate and the reading was taken by using Jenway Flame Photometer PFP-7.

3. Results:

3.1. Characterization of Soils at the Experimental Site:

Soil samples (0-15) were collected from all farmer lands of the study area before the sowing of maize. These soil samples were brought to the laboratory, air-dried, and ground for chemical analysis including soil reaction (pH), electrical conductivity (EC_e), soil organic matter (SOM), available -P, and extractable -K. Soil pH and ECe were recorded after taking an extract from the soil-saturated paste and taking readings with Hanna instruments after standardizing with standards (Richards 1954). Soil organic matter was estimated following Walkley & Black method given by Nelson & Sommers (1996). Available P was measured after extracting the soil with 0.5 M $NHCO_3$ followed by color development with ammonium molybdate the Spectrophotometer was used to obtain reading at 880 nm wavelength (Olsen & Sommers, 1982). Extractable K was measured by extracting soil with 1 N ammonium acetate and the reading was taken by using Jenway Flame Photometer PFP-7.

Table 2: Soil characteristics of Faisalabad, Sargodha and Sahiwal

Locality	EC (dS m^{-1})	pH	OM (%)	Available P (mg kg^{-1})	Extractable K (mg kg^{-1})
Faisalabad (n=36)					
Mean	2.41	8.14	0.94	6.76	165
Minimum	0.94	7.70	0.52	4.10	80
25th Percentile	1.90	8.10	0.71	5.60	120
Median	2.33	8.10	0.78	6.70	170
75th Percentile	3.10	8.23	0.86	7.53	180
Maximum	3.50	8.40	6.30	10.70	360
SD	0.72	0.15	0.93	1.55	57.0
Sargodha (n=11)					
Mean	1.47	7.80	0.75	5.52	157
Minimum	0.95	6.90	0.62	3.10	116
25th Percentile	1.29	7.80	0.71	5.25	139
Median	1.50	7.90	0.76	5.50	164
75th Percentile	1.66	8.00	0.81	6.20	178
Maximum	1.88	8.10	0.90	6.80	198
SD	0.28	0.33	0.08	0.98	26.6
Sahiwal (n=10)					
Mean	2.10	8.16	0.62	7.96	185
Minimum	1.10	7.80	0.37	3.50	120
25th Percentile	1.33	8.13	0.52	6.75	143
Median	1.65	8.20	0.67	8.10	165
75th Percentile	2.85	8.20	0.71	8.38	195
Maximum	3.75	8.40	0.75	12.80	340
SD	0.99	0.16	0.13	2.47	68.0

3.2. Effect of Nutrient Level on Fodder Yield:

The results of the study at all experimental sites showed that the application of N-P-K significantly increased maize fodder yield during all the experimental years (2015-2019). It was observed that with increasing N dose from 0 to 195 kg ha^{-1} (T_2 to T_5), the green fodder yield was increased from 31.76 to 53.48 t ha^{-1}, respectively. Similarly, the increasing P application from 0 to 90 kg ha^{-1} increased the fodder yield from 35.45 to 54.25 t ha^{-1}. The increasing trend of increasing fodder yield was also followed after K application and with increasing K application from 0 to 45 kg ha^{-1}, the fodder yield was increased from 47.79 to 51.58 t ha^{-1}, respectively.

In this study, T_4 (N-P_2O_5-K_2O @ 130-60-30 kg ha^{-1}) was based on the recommended doses of all three nutrients *i.e.,* N-P-K. This dose produced 49.88 t ha^{-1} fodder yield (Table 3). It was noted that by increasing the N rate following this recommended dose from 130 to 195 kg and P from 60 to 90 kg ha^{-1} (in the case of T_5 and T_8), the fodder yield increased to 53.48 and 54.23 t ha^{-1}, respectively, although the increase in fodder yield was statistically similar. But this was the maximum fodder maize yield observed in this study. Similar results were obtained during all four years for both N and P applications. On an overall basis, the increase of K from 30 to 45 kg ha^{-1} also increased the fodder yield from 47.79 to 51.58 t ha^{-1} but the magnitude of the increase did not match the increase observed after application of N and P. However, during 2016 and 2018, K doses of 30 and 45 kg ha^{-1} were statically at par with each other (T_4 vs T_{11}) which revealed that 30 kg ha^{-1} of K_2O was sufficient for maize fodder. Additionally, it was observed that maize fodder yield was statistically at par when compared location wise indicating that there was no difference due to changes in environmental conditions.

The spontaneous response to N and P beyond the recommended doses is attributed to the hidden hunger the of soil fertility status of studied soils. It has already been studied that most of the Pakistani soils are alkaline calcareous. Such soils are prone to heavy N losses and P fixation.

Table 3: Effect of N-P-K on maize fodder yield (t ha^{-1}) (2015-19)

Treatment	Faisalabad	Sargodha	Sahiwal	Mean
Number of sites	36	11	10	57
T1	21.854i	20.925f	25.019g	22.956i
T2	28.516h	37.306e	38.812f	31.756h
T3	39.650f	45.522d	43.645de	41.550f
T4	50.363bc	52.458c	46.844bc	49.878bc
T5	52.704a	58.518ab	51.1804a	53.484a
T6	31.340g	40.303e	45.207e	35.450g
T7	43.781e	46.970d	45.426bc	44.708e
T8	53.839a	59.057a	50.604a	54.226a
T9	48.208d	50.067c	45.207cd	47.790d
T10	49.451cd	50.020c	46.918b	49.236cd
T11	51.151b	55.983b	49.722a	51.576b
$LSD_{0.05}$	1.32	3.06	1.68	1.78

3.4. Economics of Nutrients:

When the fodder maize yield data of treatments of the present study was compared on the basis of benefit-cost ratio, the highest BCR *i.e.,* 7.77 was observed with zero P dose (T_6) (Table 4) but the maize fodder yield was very low (35.45 t ha^{-1}) with low gross benefit of Rs. 1,77,250 ha^{-1}. It was followed by T_7 (130-30-30 kg ha^{-1}) with a BCR of 6.21 with a gross benefit of Rs. 2, 23,550 ha^{-1}. Following this, T_9 (130-60-0 kg ha^{-1}) and T_{10} (130-60-15 kg ha^{-1}) with BCRs of 5.95 and 5.51, respectively. These two fertilizer doses gave gross benefits of Rs. 2, 38,950 and 2, 46,200 ha^{-1}, respectively. Moreover, on the basis of gross benefit, T_8 (130-90-30 kg ha^{-1}) and T_5 (195-60-30 kg ha^{-1}) were at the top with Rs. 2, 71,150, and 2, 67,400 ha^{-1}, respectively, during all study years which were also statistically similar in yield. On the basis of net benefit, the maximum net benefit was obtained from T_5, T_8, and T_{11} which was Rs. 2, 11,306, Rs. 2, 08,746, Rs. 2, 04,184, respectively.

Analysing the data on the basis of the rate of return, and the marginal rate of return of three nutrient elements *i.e.,* N-P-K, it was observed that these were found positive for nutrient levels used in this study (Table 4). The marginal rate of return of fertilizer application is known to decrease with increasing doses of fertilizer. In this study, with increasing N dose from

130 to 195 kg ha^{-1}, the marginal rate of return for 195 N was obviously lower (2.61) but was still positive. Similarly, with an increase in P application, the fodder yield was increased and MRR for 60 and 90 kg ha^{-1} doses of P was 1.96 and 1.65, respectively. The rate of return of K application proved to be the lowest of these three major nutrients. For K, the MRRs for 15, 30, and 45 kg ha^{-1} of K_2O were 1.61, 0.71, and 1.88, respectively. However, in the present study, the BCR of 195 kg ha^{-1} of N appears better, which could be due to the higher price of fertilizer during the current study.

Table 4: Effect of N-P-K application on benefit-cost ratio (BCR) for maize fodder

Treatment # of sites	Faisalabad 36		Sargodha 11		Sahiwal 10		Overall 57	
	Benefit Rs/ha (@Rs5/kg)	BCR	Benefit Rs/ha (@Rs5/kg)	BCR	Benefit Rs/ha (@Rs5/kg)	BCR	Benefit Rs/ha (@Rs5/kg)	BCR
T1 (0 Fert.)	1,09,272	-	1,04,625	-	1,25,097	-	1,14,800	-
T2 (P&K)	1,42,581	4.02	1,86,532	5.27	1,94,061	5.48	1,58,800	4.48
T_3	1,98,249	4.69	2,27,609	5.38	2,18,222	5.16	2,07,750	4.91
T_4	2,51,814	5.12	2,62,290	5.33	2,34,222	4.76	2,49,400	5.07
T_5	2,63,523	4.70	2,92,593	5.22	2,55,898	4.56	2,67,400	4.77
T_6	1,56,698	6.87	2,01,515	8.84	2,16,231	9.48	1,77,250	7.77
T_7	2,18,904	6.08	2,34,848	6.52	2,27,130	6.31	2,23,550	6.21
T_8	2,69,195	4.31	2,95,286	4.73	2,53,019	4.05	2,71,150	4.35
T_9	2,41,038	6.00	2,50,337	6.23	2,26,037	5.63	2,38,950	5.95
T_{10}	2,47,256	5.53	2,60,101	5.82	2,34,593	5.25	2,46,200	5.51
T_{11}	2,55,753	4.76	2,79,916	5.21	2,48,609	4.63	2,57,900	4.80

Benefit = Value of crop @ Rs 5 kg^{-1}, BCR= Value of crop ÷ Fertilizer cost (Rs ha^{-1}). Only fertilizer price is taken as cost.

Table 5: Effect of N-P-K application on marginal rate of return (MRR) cost ratio for maize fodder

Treatment # of sites	Faisalabad 36		Sargodha 11		Sahiwal 10		Overall 57	
	Marginal Return (Rs/ha)	MRR	Marginal Return (Rs/ha)	MRR	Marginal Return (Rs/ha)	MRR	Marginal Return (Rs/ha)	MRR
T1 (0 Fert.)	-	-	-	-	-	-	-	-
T2 (P&K)	-2,114	-0.06	46,483	1.31	33,540	0.95	8,576	0.24
T3	48,778	7.08	34,187	4.96	17,271	2.51	42,060	6.10
T4	46,675	6.77	27,790	4.03	9,110	1.32	34,760	5.04
T5	4,818	0.70	23,413	3.40	14,786	2.15	11,110	1.61
T6	-73,535	2.21	-57,787	1.74	-6,377	0.19	-56,860	1.71
T7	49,006	3.71	20,133	1.53	-2,302	-0.17	33,100	2.51
T8	23,891	0.90	34,038	1.29	-511	-0.02	21,200	0.80
T9	-5,933	0.27	-22,725	1.02	-4,757	0.21	-9,976	0.45
T10	1,706	0.38	5252	1.16	4,044	0.90	2,738	0.61
T11	-527	-0.06	10,791	1.20	4,993	0.55	2,676	0.30

4. Discussion:

Soils are also confronted with rapid mineralization of SOM, and nutrient use efficiency (NUE) is largely associated with the presence of sufficient SOM since SOM plays a vital role in nutrient recycling and transformation (Raza *et al*., 2018). These are mechanisms behind the positive response of maize fodder to higher N-P-K application. The fertilizer doses posed better responses in the present study even applied at slightly higher than Bhagat *et al*. (2019) who reported that application of 180:90:60 kg NPK ha^{-1} (47.01 t ha^{-1}) was similar to treatments of 150:75:45 kg NPK ha^{-1} alone and 120:60:30 kg NPK ha^{-1} plus vermicompost @5 t ha^{-1} for yield parameters of maize fodder. Bekele *et al*. (2022) also reported a farmers' field study and revealed that the balanced use of nutrients is necessary for obtaining higher maize crop yields. He further identified the response differences between experiments at Nitisols and Andisols. The MRRs for K were positive which indicates that the application of K to maize fodder is economical and may be recommended for farmers. Almost similar results were obtained by Ullah *et al*. (2015) in DI Khan

Pakistan with 240 kg ha^{-1} of N having the highest BCR for producing the highest growth and quality traits. In a study carried out in Gujrat India by Meena *et al*. (2022), 120 kg N ha^{-1} produced the maximum gross and net return as well as BCR for maize fodder.

5. Conclusion:

It can be concluded from this study that fodder maize yield increased as the doses of N-P-K increased. These applications of N-P-K were also found economical on the basis of BCR and MRR. The study concludes that N-P-K applications @ 195-60-30 or 130-90-30 kg ha^{-1} are most appropriate for future use. The benefits of these doses are attributed to a better balance and combination of N-P-K ratios. However, this study also indicates a threatening scenario by anticipating the pilling up of reactive N since heavy N applications in alkaline calcareous soils can yield heavy N losses. Therefore, bioassay studies for further research are recommended.

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