Estimating Nitrogen Use Efficiency, Profitability, and Greenhouse Gas Emission Using Different Methods of Fertilization

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Fertilization is a way to better use nitrogen fertilizers and increase productivity, but in another way, fertilization is also a source of anthropogenic greenhouse gas emissions. The study was carried out to measure the profitability ratio, technical efficiency, and CO₂ from the top dressing (TD) and deep placement (DP) fertilization. The study was based on primary data, which were collected from different respondents and areas through a well-designed questionnaire. The study finds that DP fertilization is more profitable, least costly, and more efficient than TD fertilization. The finding observed that the yield of the TD growers is 727.82 kg/ha more than that of TD respondents. The efficiency score shows that to reach the 90% efficiency level, the farmers of TD need to use DP fertilization. The farmers of TD and DP can still increase their efficiency up to 12% and 9% by using the same inputs. The findings also clarify that manufacturing of synthetic nitrogen (N), direct use of N, Yield, and Area-Scaled greenhouse gas (GHG) emissions from the use of synthetic N through TD fertilization are greater than that of the DP group. The farming community needs to be aware of greenhouse gas emissions and how they can be reduced. It is also suggested that farmers need to shift toward DP fertilization to increase yield, profit, efficiency, food security, and reduce GHG emissions.

Keywords: nitrogen use efficiency, DP, TD, GHG emission, fertilization

INTRODUCTION

The rapid increase in population pressurizes the farmer community to improve productivity and overcome food shortages. With the speed at which the world population increases, it is expected that global food security and the shortage will be the foremost global challenge (Hall et al., 2017; Prosekov and Ivanova, 2018). To overcome the shortage and growing demand for food, various problems related to agricultural productivity need to be solved. Better management of land, inputs,
and fertilizer application is one of the key components of improving productivity. In the race of increasing productivity and food security, farmers ignore the anthropogenic greenhouse gas (GHG) emissions from the use of fertilization and other farm activities (Shakoor et al., 2020a; Nasrullah et al., 2021a). In 2010, approximately 11% of the worldwide anthropogenic GHG emission was due to agricultural production and activity (Tubiello et al., 2013; IPCC., 2014; Shakoor et al., 2020b). Recently, many studies measure the GHG emission from different agricultural activities (Cheng et al., 2011; Maraseni and Qu, 2016; Yue et al., 2017; Maraseni et al., 2018). The application of fertilizer contributes greatly to grain production and food safety. Fertilizers play a vital role in an increase in productivity and food safety. Still, due to the influence of traditional techniques, and lack of proper knowledge and scientific guidance, many farmers use excessive fertilizers (Miao et al., 2011; Chen et al., 2016). The rapid rise in fertilizer use and nitrogen (N) use efficiency in farmland have limited the sustainable development of agriculture and caused various environmental problems (Liu et al., 2013).

For effective plant nutrition in the growing stage of the plant, deep placement of nitrogen fertilization method is healthier than the conventional fertilization (top dressing) and cultivation (Nkebiwe et al., 2016). Deep placement of nitrogen fertilizer appears to be a potential way of reducing nitrous oxide nitrogen (N₂O–N) soil emissions (Signor et al., 2013). The N₂O–N that is emitted from the soil during the use of urea fertilizer through deep placement was 80% lower than that emitted from the soil using top dressing (Gaihre et al., 2016). Chatterjee et al. (2018) stated that N₂O–N emission can be reduced by using the deep placement of nitrogen because a greater proportion of fertilizer nitrogen may be kept in the soil for a longer period. Correspondingly, Chapuis-Lardy et al. (2006) argued that N₂O–N emission can be reduced from the soil due to the N₂O microbial consumption. Similarly, Rutkowska et al. (2017) conducted field research in Poland and stated that deep placement of nitrogen can reduce the N₂O–N emission from the soil at a rate lower than the previous literature. Linquist et al. (2012) described that deep placement of nitrogen fertilization encourages N₂O–N, whereas Adviento-Borbe and Linquist (2016) detected that the deep placement and broadcasting method of nitrogen fertilization produces an equal amount of N₂O–N emission. This inconsistency in literature and results may occur due to the difference in nitrogen fertilizer use, and soil and weather conditions (Liu et al., 2020).

The agriculture sector of Pakistan plays an essential role in rural labor capital and is a major source of the national economy. The overall contribution of the agriculture sector to the gross domestic product (GDP) is 19.3%, and this sector engages 42% of the rural labor of the country (GOP (Government of Pakistan)., 2021). Maize is considered an important crop after wheat and rice, which carries a variety of important nutrients. The total share of maize is 2.4% of the total value added, which includes agribusiness at 0.5% of the GDP of Pakistan. The total production of maize was 5.70 million tons in 2017–2018, showing a decline of approximately 7% from the previous year of production (6.13 million tons). Several factors are responsible for the low yield of maize in Pakistan. Hence to improve maize productivity in Pakistan, special agro management practices and nutrition management can maximize the maize yield. Because of the high temperature and limited organic matter in Pakistan, nitrogen availability in soil for optimum plant development and growth is quite low. As a result, it’s hard to imagine growing a crop without using nitrogen fertilizer. Therefore, this study was carried out with the following objectives:

- Measuring the profitability ratio of top dressing and deep placement fertilization method.
- Measuring the efficiency analysis of maize growers using top dressing and deep placement fertilization method.
- Comparing the GHG emission from the synthetic nitrogen used in top dressing and deep placement fertilization method.

**MATERIALS AND METHODS**

**Data and Sampling Procedure**

Maize is an important silage crop that is grown in all provinces of Pakistan but the bulk (97%) of production comes from these two provinces, namely, Punjab and Khyber Pakhtunkhwa province (GOP (Government of Pakistan)., 2021; PARC, 2022). For the collection of maize grower data, the study used a multistage sampling technique to acquire the required sample size. In the first phase, the study was carried out in Khyber Pakhtunkhwa province based on the second highest production after Punjab. In the second phase, from the four agro-ecological zones, Mardan district was selected from Zone C among 7 districts, considering the production and number of growers as shown in Fig 1. In the third phase, Tehsil Takht Bhai was carefully chosen among the three tehsils (Mardan, Katlang, and Takht Bhai). In the fourth phase, three villages were chosen randomly, namely Qandaro, Saeed Abad, and Qala Kaly. In the last phase, a direct election approach was used to interview 125 respondents using top dressing and 125 respondents using the side-dressing fertilizer method as shown in Fig 2.

**Stochastic Frontier Production Function**

Aigner et al. (1977) and Meeusen and Broeck (1977) worked independently on Farrell (1957) work and researched and developed the stochastic frontier production function. The stochastic frontier production function analysis (SFA) is unique due to the existence of a composed error term, which is different from other statistical methods. Therefore, previous studies (Sekhon et al., 2010; Musaba and Bwacha, 2014; Saddozai et al., 2015; Naveed et al., 2018; Ali et al., 2019; Jo et al., 2021) used the SFA model to measure the efficiency level due to its uniqueness. The broad method of the stochastic frontier production function can be stated as:

\[
\ln (y_j) = \beta' a_j + v_j - u_j \text{ where } j = 1, 2, \ldots, N
\]

The yield gained from the j-th farmer is represented by y_j, a_j is a K × 1 vector having the natural log of inputs applied by the j-th field, the unknown parameters can be represented by \( \beta \), and the symmetry error (v_j) shows a random variation in the output, which is distant from the control of maize growers.
due to some factors. Aigner et al. (1977) stated that vj has an independent and identical distribution, denoted as $N(0, \sigma^2v)$, which is free from uj (random nonnegative variable). Moreover, vj is related to farm-specific features that are under the control of maize growers. These farm-specific features contribute to the technical inefficiency of maize growers, within the identical and independent distribution of the exponential form as $N(0, \sigma^2u)$. In addition, Coelli et al. (2005) confirmed that the stochastic frontier model takes a precise functional form, which is as follows:

$$
\ln y_j = \beta_0 + \beta_1 \ln x_j + v_j - u_j
$$

$$
y_j = \exp(\beta_0 + \beta_1 \ln x_j + v_j - u_j)
$$

$$
y_j = \exp(\beta_0 + \beta_1 \ln x_j) \times \exp(v_j) \times \exp(-u_j)
$$

$$
\exp(\beta_0 + \beta_1 \ln x_j) = \text{deterministic component}
$$

$$
\exp(v_j) = \text{error}
$$

$$
\exp(-u_j) = \text{inefficiency}
$$

**Technical Efficiency**

Coelli et al. (2005) stated that technical efficiency is the ratio between stochastic frontier output and observed output. Therefore, the technical efficiency of maize growers is as follows:

$$
TE_i = \frac{q_i}{\exp(\beta x_i + v_i)}
$$

$$
TE_i = \frac{\exp(\beta x_i + v_i - u_i)}{\exp(\beta x_i + v_i)}
$$

$$
TE_i = \exp(-u_i)
$$

The efficiency score ranges from zero to one. A farmer is said to be more efficient, if his or her efficiency score is near one or one, and a farmer is said to be inefficient if his or her efficiency score is near zero or zero.

**Model Specification**

The Cobb–Douglas stochastic frontier model was applied to enumerate the relationship between the input and output, as used in the earlier research of Battese and Coelli (1992). The model for Mardan and Swabi districts and combined districts are...
specified below:

\[
\ln Y = \ln \beta_0 + \beta_1 \ln \text{Area} + \beta_2 \ln \text{Seed} + \beta_3 \ln \text{Tractor} \\
+ \beta_4 \ln \text{Labour} + \beta_5 \ln \text{Irrigation} + \beta_6 \ln \text{FYM} + \beta_7 \ln \text{DAP} \\
+ \beta_8 \ln \text{Urea} + \beta_9 \ln \text{Pesticides} + (V_i - U_i)
\]

Where \( \ln \) is the natural logarithm; \( Y \) represents the maize yield in kilograms per hectare; \( \beta_i \) is the parameters to be estimated; \( \text{Area} \) represents the land used for maize growing; \( \text{Seed} \) represents the seeds used in kilograms per hectare; \( \text{Tractor} \) is the tractor hours used per hectare; \( \text{Labour} \) represents the amount of labor used per hectare; \( \text{Irrigation} \) represents the number of irrigations per hectare during growth; \( \text{FYM} \) represents the Farm Yard Manure used in trolley per hectare; \( \text{DAP} \) is the Di-ammonium phosphate used in kilograms per hectare; \( \text{Urea} \) represents the urea used in kilograms per hectare; \( \text{Pesticides} \) is the amount of pesticide sprayed per hectare.

**Equation of Technical Inefficiency Estimation**

The following function was used to measure the various inefficiency factors that can reduce maize production in the respondent area:

\[
U_i = \delta_0 + \delta_1 (\text{Age}) + \delta_2 (\text{Edu}) + \delta_3 (\text{Exp}) + \delta_4 (\text{FamS}) \\
+ \delta_5 (\text{Credit}) + \delta_6 (\text{Exte}) + \delta_7 (\text{Occu}) + \delta_8 (\text{CertS}) \\
+ \delta_9 (\text{DistMarket}) + \delta_{10} (\text{OfIncome}) + \delta_{11} (\text{Tenan}) \\
+ \delta_{12} (\text{Television}) + \delta_{13} (\text{Livestock})
\]

where \( U_i \) represents inefficiency effect; \( \delta_i \) represents the unknown parameters to be estimated; \( \text{Age} \) represents the age of the maize growers in years; \( \text{Edu} \) represents the education level of the maize growers in schooling years; \( \text{Exp} \) represents the experience of maize growers in years; \( \text{FamS} \) represents the family size of maize growers in numbers; \( \text{Credit} \) represents the agricultural credit obtained in rupees; \( \text{Exte} \) represents the number of visits by extension agents during the growing period; \( \text{Occu} \) is the dummy variable for respondent occupation other than farming and is equal to 1 otherwise, it is 0; \( \text{CertS} \) is a dummy variable for certified seed equal to 1; \( \text{DistMarket} \) is the distance of the field from the local market in kilometers; \( \text{Of Income} \) is a dummy variable for off-farm income and is equal to 1 otherwise, it is 0; \( \text{Tenan} \) is a dummy variable for tenancy and is equal to 1 (landowner) otherwise, it is 0 (renter); \( \text{Livestock} \) is a dummy variable for holding livestock and is equal to 1 otherwise, it is 0; \( \text{Television} \) is a dummy variable for a farmer using a Television and is equal to 1 otherwise, it is 0.
**GHG Emissions From Urea Manufacture**

During the manufacturing of synthetic nitrogen, the greenhouse gases (GHG) emission includes consumption of fossil fuel, transportation, ammonia synthesis, mining, and changing ammonia to various artificial N fertilizer products (Zhang et al., 2013). For the GHG emission during the manufacturing of urea fertilizer, this study used the local GHG emission factors for urea fertilizer in Pakistan. Mir and Ijaz (2016) estimated the GHG emission factors during the manufacturing of urea fertilizers in Pakistan. The average level of GHG emission during the manufacturing of urea was estimated as 1.5 kg CO\(_2\) emission from the manufacturing of 1 kg of urea. Therefore, the GHG emission during the manufacturing of urea used by the top dressing and deep placement is calculated by using the following equation:

\[
M_E = A_u \times A_{rea} \times E_{Factor}
\]

Where \(M_E\) signifies the GHG (kg CO\(_2\)-equal which means describing different greenhouse gases in a common unit) emission from the manufacturing of urea which is used during maize production, \(A_u\) signifies the amount of urea used in kilograms during maize production. \(A_{rea}\) signifies the area under the maize production and \(E_{Factor}\) is the estimated factor (1.5 kg CO\(_2\)/kg urea) for urea in Pakistan [Mir and Ijaz (2016)]. The study also applies an ordinary least square method to measure the elasticity of variables using the following equation:

\[
Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \epsilon_i
\]

Where \(Y\) represents the manufacturing emissions in kg CO\(_2\)-eq, \(X_1\) represents the area under maize in hectares and \(X_2\) represents the amount of urea in kg, \(\beta_1 \text{ and } \beta_2\) are the slopes of \(X_1\) and \(X_2\), \(\beta_0\) in the intercept of the model, and \(\epsilon_i\) is a random error of the model.

**Direct N\(_2\)O Emissions From Urea Fertilization**

The direct nitrous oxide (N\(_2\)O) emissions from the use of nitrogen were estimated from the IPCC guidelines for national GHG inventories (IPCC, 2006; tier 1) pooled with the crop-specific direct N\(_2\)O emission and agro-region factors for the upland field were 0.010 kg N\(_2\)O-N/kg of nitrogen (IPCC, 2006). Whereas, the amount of nitrogen available in urea is 46%. Hence, to measure the direct N\(_2\)O-N emission from the fertilization of urea used by the respondent is 0.01(1%) kg N\(_2\)O-N/kg of urea. The emission factor value obtained from the IPCC, 2006 equation for the direct N\(_2\)O-N emission from the managed soil is as follows:

\[
N_2O_{Direct} - N = N_2O - N_N inputs + N_2O - N_{ut} + N_2O - N_{PRP}
\]

Where \(N_2O_{Direct} - N\) is the direct N\(_2\)O–N emissions, \(N_2O - N_N inputs\) is the N\(_2\)O–N emissions from N inputs, \(N_2O - N_{ut}\) is the N\(_2\)O–N emissions from managed organic soils, and \(N_2O - N_{PRP}\) is the N\(_2\)O–N emissions from urine and dung inputs. The direct emission from the urea used in the study area can be measured by using the following formulation:

\[
D_E = A_N \times A_{rea} \times E_{Factor} \times 44/28
\]

Where \(D_E\) signifies the N\(_2\)O (kg N\(_2\)O) emission from the application of urea used for maize in the respondent area, \(A_N\) signifies the amount of nitrogen fertilizer used by the respondent in kilograms during maize production whereas \(A_{rea}\) signifies the area under the maize production, \(E_{Factor}\) is the estimated factor of N\(_2\)O–N (0.010 kg N\(_2\)O–N/kg of nitrogen) and the fraction 44/28 converts N to N\(_2\)O. The study also applies an ordinary least square method to measure the elasticity of variables using the following equation:

\[
Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \epsilon_i
\]

Where \(Y\) represents the manufacturing emissions in kg N\(_2\)O–N, \(X_1\) represents the area under maize in hectares, and \(X_2\) represents the amount of synthetic N in Kg, \(\beta_1 \text{ and } \beta_2\) are the slopes of \(X_1\) and \(X_2\), \(\beta_0\) in the intercept of the model, and \(\epsilon_i\) is a random error of the model.

The yield-scaled and area-scaled (kg CO\(_2\)-eq/ha) GHG emission from the use of urea for maize in the respondent area were estimated accordingly:

\[
Yield \text{- scaled GHG emissions} = \frac{[ME + (DE \times 298)]}{Yield}
\]

Where 298 is the radiative forcing constant of N\(_2\)O relative to CO\(_2\) at a 100-year time horizon (Forster et al., 2007; IPCC, 2007; Sosulski et al., 2020).

**RESULTS**

**Descriptive Statistics of Variables**

The descriptive statistics of the main variables used in the SFA model are shown in Table 1. The estimated average maize yield of top dressing and deep placement fertilization practices was 3,161.86 and 3,889.68 kg/ha. The estimate results show a significant difference in the average yield of maize in the respondent area. The paired t-test value proved a significant mean difference in maize yield (727 kg/ha) of deep placement and top-dressing fertilization. The average seed used by the top-dressing and deep placement group was 9.96 and 9.36 kg/ha with a significant t-value (1.85). The t-ratio at a 10% significance level shows that the seed used by the top-dressing group is 0.6 kg/ha more than the deep placement group. Likewise, the average labor used by TD and DP was 19.10 and 18.46 person/ha with an insignificant t-value. This result implies that both TD and DP use the same number of labor per hectare. Similarly, the mean value of land used by the respondent in the study area for top and deep placement fertilization was observed at 2.22 and 2.16 ha (1 hectare = 2.47 acres) showing that the area under maize used in both kinds of fertilization is almost the same.

The observed statistics show that the average irrigation applied by the TD and DP was 5.58 and 5.99 times with a significant mean difference of 0.40 times. The results show that DP group farmers use more water as compared to the TD group. The mean farmyard manure used by the TD and DP was 1.95 and 1.93 trolley (1 trolley = 500 kg of manure) ranging from 1 to 4 trolleys. It was observed that both groups of fertilization are
The descriptive statistics of farmers’ attributes and socio-economic factors are described in Table 2. The mean age observed for the TD and DP respondents were 44.13 and 42.54 years, respectively, while the education level was 8.27 and 7.88 schooling years, respectively. The results show that farmers’ mean age and education of TD and DP groups are the same. It is also observed that the average experience of the TD and DP respondents was 13.14 and 16.29 years, whereas the average family size was 8.62 and 9.27 persons, respectively. The average amount of agriculture credit received by the TD and DP respondents observed was 80.68 × 10^3 and 80.83 × 10^3 Pakistani rupees, respectively, while the mean extension visit was 0.88 and 1.12 times, respectively, in the study area. Similarly, the respondents engaged in other occupation along with agriculture was observed at 0.51 and 0.39 in the TD and DP group while the mean certified seed used was 0.61 and 0.64, respectively. The mean distance between field and market was 3.15 and 3.64 km was observed for the TD and DP groups while the farmers who received their incomes from other sources were 0.49 and 0.42, respectively. The descriptive also shows that the average tenancy, television used by the respondents, and livestock were 0.50, 0.49, and 0.68 for the TD group, while 0.58, 0.37, and 0.72 were observed for the DP group.

Cost and Net-Return of Maize Production (Per Hectare)

The study also measures the cost and net return of top dressing and deep placement which is shown in Table 3. The estimated results show that the tractor used for plowing and seedbed preparation incurred the highest average cost of 20.14% and 20.80% of the total cost on top and deep placement while the average rental cost of the land is the second most costly input used by both groups. The cost spent on land was 19.18% of

| TABLE 1 | Descriptive statistic of major variables used in the SFA model. |
|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Variables      | Top Dressing (Min–Max) | Deep placement (Min–Max) | Total Sample (Min–Max) | t-test |
|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Yield (kg ha⁻¹) | 3,161.86 ± 688.48 | 3,889.68 ± 715.79 | 3,525.77 ± 788.74 | 727.82± | 1.85*** |
| Seed (kg ha⁻¹)  | 9.96± ± 2.74     | 9.36 ± 2.06     | 9.66 ± 2.44     | 1.99     | 0.06 |
| Labor (No ha⁻¹) | 19.10 ± 4.03     | 18.46 ± 4.08     | 18.84 ± 3.87     | 0.50     | 0.06 |
| Area (Ha)       | 2.22 ± 1.00      | 2.16 ± 0.97      | 2.19 ± 0.99      | 0.64     | 0.41* |
| Irrigation      | 5.58 ± 0.64      | 5.99 ± 0.70      | 5.79 ± 0.70      | 1.42     | 0.02 |
| FYM (Number)    | 1.95 ± 1.34      | 1.93 ± 1.32      | 1.95 ± 1.25      | 0.70     | 0.05 |
| DAP (kg ha⁻¹)   | 37.86 ± 8.36     | 39.32 ± 7.04     | 38.59 ± 7.70     | 1.47     | 0.05 |
| Urea (kg ha⁻¹)  | 150.24 ± 58.74   | 108.82 ± 39.57   | 129.53 ± 54.12   | 41.14*   | 0.02 |
| Tractor (hrs)   | 9.75 ± 1.79      | 10.03 ± 1.99     | 9.87 ± 1.89      | 0.70     | 0.05 |
| Pesticide       | 1.42 ± 0.49      | 1.42 ± 0.49      | 1.42 ± 0.49      | 0.70     | 0.05 |
| Nitrogen (kg)   | 69.11 ± 27.02    | 50.06 ± 18.20    | 59.58 ± 24.89    | 19.05*   | 0.05 |

Survey data 2021. The *, ** and *** shows the significant difference at 1%, 5% and 10%.

| TABLE 2 | Descriptive statistics of inefficiency variable used in SFA. |
|----------------|-----------------|-----------------|-----------------|-----------------|
| Variables      | Top Dressing (Min–Max) | Deep placement (Min–Max) | Total Sample (Min–Max) | t-test |
|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Age (Years)    | 44.13 ± 6.17    | 42.54 ± 6.26    | 43.33 ± 6.25    | 27(58–58)       |
| Education (Years) | 8.27 ± 4.29 | 8.08 ± 4.11 | 0.00–4.00 |
| Experience (Years) | 13.14 ± 7.79 | 14.72 ± 7.35 | 0.00–4.00 |
| Family size (Number) | 8.62 ± 2.52 | 8.95 ± 2.64 | 0.00–4.00 |
| Credit in PKR (x10³) | 80.88 ± 122.34 | 80.83 ± 132.24 | 80.76 ± 127.13 | 0.00–140.80 |
| Extension agent visit (Number) | 0.88 ± 0.69 | 1.00 ± 0.73 | 0.00–0.02 |
| Other occupation | 0.51 ± 0.50 | 0.45 ± 0.50 | 0.00–0.01 |
| Certified seed (kg) | 0.61 ± 0.49 | 0.62 ± 0.49 | 0.00–0.01 |
| Distance from market (Km) | 3.15 ± 1.90 | 3.39 ± 1.96 | 0.00–2.00 |
| Off-farm income (kg) | 0.49 ± 0.50 | 0.47 ± 0.50 | 0.00–0.01 |
| Tenancy (kg) | 0.50 ± 0.50 | 0.54 ± 0.50 | 0.00–0.01 |
| Television (kg) | 0.49 ± 0.50 | 0.42 ± 0.49 | 0.00–0.01 |
| Livestock (kg) | 0.68 ± 0.47 | 0.70 ± 0.46 | 0.00–0.01 |

Survey data 2021.

The study measures the cost and net return of top dressing and deep placement which is shown in Table 3. The estimated results show that the tractor used for plowing and seedbed preparation incurred the highest average cost of 20.14% and 20.80% of the total cost on top and deep placement while the average rental cost of the land is the second most costly input used by both groups. The cost spent on land was 19.18% of

Survey data 2021.
the maize total cost for the TD group while 19.57% of the total cost for the DP group. It is also observed that the mean labor cost was 14.09 and 14.18% of the total cost incurred by TD and DP respondents, respectively. The fourth highest cost input was urea in the study area. The cost incurred by TD and DP was 12.41 and 10.92% of the total cost while transportation cost was the least cost incurred by the TD and DP group. The total cost of maize production per hectare was observed at 67,787 PKR/ha on top-dressing fertilization while on side-dressing the total cost was 66,421.4 PKR/ha. The estimated results show that the net revenue gained by top dressing was 71,187.8 PKR/ha while net revenue gained by side-dressing farmers was 172,087.2 PKR/ha. The profitability ratio portrays that the deep placement fertilization method was a more profitable and least cost method as compared to the top-dressing fertilization.

Correlation Analysis
The correlation analysis was carried out among the variables of TD, DP, and the total sample model was carried out as shown in Tables 4–6. The estimated results show a weak correlation among all the variables input used in the study. These results verify that the impact of each variable input on the production of maize was not affected by the use of other variables. Therefore, the estimated results of the SFA model for TD, DP, and total sample model are unbiased.

Estimated Results of the SFA Model for TD, DP, and Total Data
The estimated output of the stochastic frontier model for top dressing, deep placement, and total sample are shown in Table 7. The projected result of seed used by the TD, DP, and total sample respondents are statistically significant at 1, 10, and 1% significant levels, respectively. The results portray that an increase of 1% in seed rate can significantly increase the yield of TD, DP, and total sample respondents by 0.11%, 0.05%, and 0.08%. The estimated results of seed rate show that both TD and DP groups are using quality seed of maize but the elasticity of seed for TD is more than DP, which implies that the seed quality and seedbed of TD is better than DP (Saddozai et al., 2015; Nasrullah et al., 2021b). Similarly, the number of labor used for TD and DP also shows a significant effect on the maize yield at a 1% and 5% significant level. The significant impact of labor shows the better management of labor used by both groups. The results are similar to the previous studies of Ali et al. (2019) and Jo et al. (2021).

The area used by the respondents also plays a significant role in the production. The projected elasticity of the area shows a 0.64% and 0.02% increase in maize production of TD and DP groups if there is a 1% increase in the area. The results are coinciding with the previous studies of Nasrullah et al. (2019) and Zulfiqar et al. (2020a), which stated that soil fertility and better management of land can increase production. Likewise, the irrigation application in the projected area is also significant at a 1% significance level for both TD and DP. The results are similar to the previous studies by Traore et al. (2000) and Payero et al. (2009), which specified that on-time irrigation can increase productivity while water stress can decrease the maize production and kernel size. The Farmyard manure also shows a substantial rise in the production of maize. The maize production can be increased by 0.007% and 0.005% with an increase of 1% in FYM. Naveed et al. (2018) stated that FYM provides micronutrients to the maize crop and increases productivity.
TABLE 4 | Pearson’s correlation analysis of top-dressing fertilization.

|          | Yield | area  | irrigation | Seed   | FYM   | DAP   | Urea  | Labor | Tractor | pest        |
|----------|-------|-------|------------|--------|-------|-------|-------|-------|---------|-------------|
| Yield    | ↑     | 1     |            |        |       |       |       |       |         |             |
| area     |       | ↓     | 0.4216     | 1      |       |       |       |       |         |             |
| irrigation|       | ↓     | 0.0564     | 0.1758 | 1     |       |       |       |         |             |
| Seed     |       |       | ↓          | 0.234  | ↓     | -0.007| 0.0056| 1     |         |             |
| FYM      |       |       |            | 0.0841 | ↓     | -0.125| -0.099| 0.1516| 1       |             |
| DAP      |       |       |            | 0.284  | 0.027 | -0.21 | 0.1636| 0.0267| 1       |             |
| Urea     |       |       |            | 0.3543 | 0.1984| -0.161| 0.0314| 0.0124| 0.129   |             |
| Labor    |       |       |            | 0.4116 | 0.261 | 0.0314| 0.1244| 0.1408| 0.0824  | 0.3313      |
| Tractor  |       |       |            | 0.439  | 0.2306| -0.017| 0.1382| 0.1144| 0.246   | 0.2373      |
| pest     |       |       |            | 0.1068 | -0.025| 0.0162| 0.1265| 0.0667| -0.087  | -0.131      |

Survey data 2021. The color green and yellow indicates the maximum and minimum value of correlation, similarly, the green, yellow and red arrow indicates the maximum, medium and minimum correlation.

TABLE 5 | Pearson’s correlation analysis of deep placement fertilization.

|          | Yield | area  | Irrigation | Seed   | FYM   | DAP   | Urea  | Labor | Tractor | pest        |
|----------|-------|-------|------------|--------|-------|-------|-------|-------|---------|-------------|
| Yield    | ↑     | 1     |            |        |       |       |       |       |         |             |
| area     |       | ↓     | 0.3866     | 1      |       |       |       |       |         |             |
| Irrigation|       | ↓     | 0.3054     | 0.1713 | 1     |       |       |       |         |             |
| Seed     |       |       | ↓          | 0.4931 | 0.2472| 0.1944| 1     |       |         |             |
| FYM      |       |       |            | 0.6289 | 0.1801| 0.0516| 0.282 | 1     |         |             |
| DAP      |       |       |            | 0.1435 | 0.2286| 0.0994| 0.203 | 0.0017| 1       |             |
| Urea     |       |       |            | 0.5859 | 0.358 | 0.242 | 0.4495| 0.3549| 0.141   |             |
| Labor    |       |       |            | 0.6465 | 0.2951| 0.1919| 0.411 | 0.4224| 0.1204  | 0.4272      |
| Tractor  |       |       |            | 0.5672 | 0.1959| 0.2946| 0.4058| 0.3595| 0.0798  | 0.4641      |
| pest     |       |       |            | 0.3377 | 0.1702| 0.033 | 0.1587| 0.1577| 0.013   | 0.2852      |

Survey data 2021. The color green and yellow indicates the maximum and minimum value of correlation, similarly, the green, yellow and red arrow indicates the maximum, medium and minimum correlation.

TABLE 6 | Pearson’s correlation analysis of total sample model.

|          | Yield | area  | irrigation | Seed   | FYM   | DAP   | Urea  | Labor | Tractor | pest        |
|----------|-------|-------|------------|--------|-------|-------|-------|-------|---------|-------------|
| Yield    | ↑     | 1     |            |        |       |       |       |       |         |             |
| area     |       | ↓     | 0.3445     | 1      |       |       |       |       |         |             |
| irrigation|       | ↓     | 0.2958     | 0.157  | 1     |       |       |       |         |             |
| Seed     |       |       | ↓          | 0.2452 | 0.102 | 0.0489| 1     |       |         |             |
| FYM      |       |       |            | 0.315  | 0.0239| -0.022| 0.2048| 1     |         |             |
| DAP      |       |       |            | 0.2356 | 0.1139| -0.034| 0.1866| 0.0144| 1       |             |
| Urea     |       |       |            | 0.1828 | 0.2487| -0.103| 0.2046| 0.1386| 0.0854  |             |
| Labor    |       |       |            | 0.4345 | 0.2781| 0.0873| 0.2458| 0.274 | 0.092   | 0.3604      |
| Tractor  |       |       |            | 0.4832 | 0.2092| 0.1692| 0.2435| 0.2408| 0.1697  | 0.2704      |
| pest     |       |       |            | 0.2031 | 0.0709| 0.0262| 0.1369| 0.1118| -0.04   | 0.03       |

Survey data 2021. The color green and yellow indicates the maximum and minimum value of correlation, similarly, the green, yellow and red arrow indicates the maximum, medium and minimum correlation.

The DAP used by the respondents has significantly improved the maize yield by 0.096% and 0.053% at a 5% significance level. Chen et al. (2020) demonstrated that DAP used for maize increases productivity. Similarly, the impact of urea is also statistically significant at a 1% significance level. The results show that a 1% increase in urea increases the maize production by 0.118% and 0.064% of TD and DP respondents. This result indicates that an accurate amount of fertilizer was used at a suitable subsidized price (Ali et al., 2019). The tractor used for seedbed preparation has an effective impact on the production
TABLE 7 | Maximum likelihood estimation.

| Variables          | Top Dressing | Deep Placement | Total Sample |
|--------------------|--------------|----------------|--------------|
|                    | Coefficient  | Coefficient    | Coefficient  |
|                    | (Std. Error) | (Std. Error)   | (Std. Error) |
| Constant           | 5.326a       | 7.054a         | 6.455a       |
|                    | (0.281)      | (0.145)        | (0.153)      |
| Seed (kg ha-1)     | 0.112a       | 0.048b         | 0.081a       |
|                    | (0.034)      | (0.025)        | (0.023)      |
| Labor (No ha-1)    | 0.231a       | 0.076b         | 0.184a       |
|                    | (0.052)      | (0.034)        | (0.032)      |
| Area/(Hectare)     | 0.064a       | 0.018b         | 0.035a       |
|                    | (0.019)      | (0.009)        | (0.011)      |
| Irrigation (Frequency) | 0.284a   | 0.113a         | 0.171a       |
|                    | (0.099)      | (0.036)        | (0.047)      |
| FYM (Trolley)      | 0.007a       | 0.005b         | 0.008a       |
|                    | (0.003)      | (0.003)        | (0.002)      |
| DAP (kg ha-1)      | 0.096b       | 0.053b         | 0.071a       |
|                    | (0.043)      | (0.026)        | (0.028)      |
| Urea (kg ha-1)     | 0.118a       | 0.064a         | 0.063a       |
|                    | (0.052)      | (0.017)        | (0.016)      |
| Tractor (h ha-1)   | 0.162a       | 0.104a         | 0.097a       |
|                    | (0.061)      | (0.026)        | (0.031)      |
| Pesticide (No ha-1)| 0.123a       | 0.044a         | 0.054a       |
|                    | (0.029)      | (0.014)        | (0.016)      |
| Top dressing       | -0.115a      | -0.276a        | -0.128a      |
|                    | (0.017)      | (0.042)        | (0.024)      |
| Lambda (λ)         | 2.018        | 2.081          | 2.156        |
|                    | (0.032)      | (0.052)        | (0.042)      |
| Γ = λ² /1 + λ²      | 0.802        | 0.812          | 0.823        |
|                    | (0.002)      | (0.002)        | (0.002)      |
| Log-likelihood     | 55.596       | 124.522        | 146.480      |

Survey data (2021). The a, b indicates the significance level at 1% and 5% respectively.

of maize in the study area. The increase of 1% in tractor hours can increase the productivity by 0.162% and 0.104% of TD and DP respondents. The machinery used for inverting and plowing land had a direct relation with production (Sekhon et al., 2010; Nasrullah et al., 2019). Likewise, pesticides used by respondents in the study area significantly improve maize production by 0.123% and 0.044% with a 1% increase in pesticide use. The results are similar to the previous study by Popp et al. (2013), which stated that a reduction in crops occurs due to pests.

The dummy variable used for top dressing in the whole model is significant with a negative coefficient implying that the deep placement method is better for productivity as compared to top dressing. The variance parameter Lambda ($\lambda$) is >1 showing that our model is a good fit while Gamma ($\Gamma$) shows that the unexplained inefficiency variable can cause 80% and 81% variation in maize production of TD and DP.

Technical Efficiency Ranges for the TD and DP Respondents

The ranges and frequency distribution of respondents’ efficiency levels are published in Table 8 for the TD and DP groups. The estimated result illustrates that the mean efficiency level of TD and DP was 87 and 90%, respectively. The demonstrated results verify a substantial difference between the TD and DP efficiency levels. The projected efficiency of the DP group was 3% less than that of the TD group, representing a significant gap between the two groups. Purucker and Steinke (2020) stated that deep placement fertilization reduces nitrogen losses and increases the efficiency level. The study further shows a gap of 12% and 9% from the mean to maximum efficiency of TD and DP groups, which implies that TD and DP group can increase their efficiency up to 12 and 9%, respectively, with a given amount of inputs. Figure 3 shows that the cumulative frequency distribution of the efficiency score of the TD and DP groups was concave to the origin, which implies that some factors affect the efficiency level of farmers.

Technical Inefficiency Estimation Model of the TD and DP Groups

The demographic, institutional, and socioeconomic factors that increase the inefficiency level of maize growers are explained in Table 9. The negative coefficient of the variable in the inefficiency model showed a positive impact on the efficiency level of farmers, while the positive sign of the coefficient showed a negative impact. The inefficiency factor age has a significant positive effect on the efficiency level of maize growers in TD and DP groups. The increase in age showed the weak physical condition of the growers (Saddozai et al., 2015; Bayisenge et al., 2019). The education level of maize growers showed a significant effect on the efficiency level of the maize growers in the TD and DP groups at the 10% and 5% significance levels. The significant impact of education showed the improved skills of the farmers, which is a key indicator of achieving improved technology. Previous studies by Dhungana et al. (2004) and Mariano et al. (2010) stated that education plays an important role in adopting new technology while Rios and Shively (2005) stated that higher education decreases the efficiency level.

The significant coefficient of farmers’ experience at 10 and 5% levels for the TD and DP groups showed that farmers have a long connection with farming activities and can easily adopt advanced technology (Bayisenge et al., 2020; Zulfiqar et al., 2020b). Similarly, the family size of the respondents is also significant for TD and DP. The noteworthy impact of family size is similar to that in the study by Coelli et al. (2002), which stated that a large family is labor intensive. Institutional factor extension agent visits to maize growers had a significant impact on maize production at the 1 and 10% level for the TD and DP groups. The results are similar to those of a previous study by Alene and Hassan (2006), which stated that a weak connection of extension agents with farmers decreased the production level of the growers. The estimated coefficient of main occupation other than agriculture had an inverse impact on the production level of the maize farmers for both groups at the 5% level. Chen (2017) stated that farmers engaged in other occupations (part-time farming) along with farming reduces the productivity and efficiency level of growers.

The estimated elasticity of certified seeds for the TD and DP groups were 0.96 and 0.66, respectively, which were significant at the 1 and 10% levels. The estimated results of the certified seeds
TABLE 8 | Efficiency ranges of the TD and DP groups.

| Efficiency Ranges | Top Dressing |  | Deep placement |  | Total Sample |  |
|-------------------|--------------|----------------|----------------|----|--------------|----|
|                   | Frequency    | Percentage     | Frequency      | Percentage   | Frequency | Percentage |
| 55–60             | 0            | 0              | 0              | 0            | 2         | 0.8        |
| 61–65             | 4            | 4              | 6              | 4.8          | 5         | 2          |
| 66–70             | 8            | 8              | 10             | 8            | 19        | 7.6        |
| 71–75             | 6.4          | 6.4            | 6              | 4.8          | 25        | 10         |
| 76–80             | 13.6         | 13.6           | 3              | 2.4          | 28        | 11.2       |
| 81–85             | 10.4         | 10.4           | 12             | 9.6          | 14        | 5.6        |
| 86–90             | 10.4         | 10.4           | 11             | 8.8          | 20        | 8          |
| 91–95             | 13.6         | 13.6           | 20             | 16           | 41        | 16.4       |
| 96–100            | 33.6         | 34.4           | 57             | 45.6         | 96        | 38.4       |
| Total             | 125          | 100            | 125            | 100          | 250       | 100        |

Survey data (2021).

FIGURE 3 | Cumulative distribution of the efficiency scores for TD and DP groups.

were in line with the results of the study by Musaba and Bwacha (2014). Distance of field from the market significantly decreases the efficiency level of growers. The results were similar to those of the previous study by Ali et al. (2019) and Nasrullah et al. (2020). The increase in off-farm income significantly decreases the efficiency level of both groups. Off-farm income activities reduce the inefficiencies of TD respondents while increasing the efficiency of DP respondents. Off-farm income not only decreases the availability of labor but also the incomes are not used sufficiently for on-farm activities of TD while DP respondents
use their off-farm income in the field (Abdulai and Huffman, 2000; Kramol et al., 2013). Similarly, the tenancy status of the growers also increases the efficiency level in the study area. Chen (2017) stated that ownership (titled land) can encourage agricultural production. Television contributes a significant role in the efficiency of respondents. Farmer’s access to television can get information related to agriculture, technology, climate, and others, and their best practices increase their efficiency (Areal et al., 2020). In the current study, agricultural credit and livestock have no impact on the efficiency level of farmers.

**GHG Emissions From Urea Manufacture for Maize**

Nitrogen is one of the key factors for maize growth, yield, and profitability (Khan et al., 2008). By considering the application rate (Urea * 0.46 = nitrogen) of nitrogen by individuals, the GHG emission from the manufacturing of synthetic N consumed by top-dressing and deep placement fertilization are shown in Table 10. The results show that the total CO2 emitted from the manufacturing of synthetic N used by TD farmers was 29,716 MtCO2 equal while the CO2 emitted from the manufacturing of N used by DP farmers was 21,443 MtCO2—. The estimated GHG emission shows that 8.273 MtCO2 of carbon can be reduced from the manufacturing of synthetic N if the farmers of TD shift toward deep placement fertilization. Similarly, the average GHG emission by the TD and DP farmers was 237.72 and 171.54 kgCO2/ha, respectively, which implies that each farmer of the DP group can reduce GHG emission by 66.18 kgCO2/ha from the manufacturing of synthetic N if they shift toward deep placement. The estimated results are similar to the previous study by Chai et al. (2019). The estimated results of OLS show that area and urea have a significant impact on the manufacturing emission at a 1% significant level. An increase of 1 unit in area and urea can increase the manufacturing emission by 108.70 and 1.50 kgCO2.

### TABLE 9 | Inefficiency factors of TD and DP groups.

| Variables                  | Coefficient (Std. Error) | Coefficient (Std. Error) | Coefficient (Std. Error) |
|----------------------------|--------------------------|--------------------------|--------------------------|
| Constant                   | −8.125a                  | −3.123c                  | −5.067a                  |
| Age (Years)                | 0.076b                   | 0.054c                   | 0.063a                   |
| Education (Years)          | −0.105c                  | −0.084b                  | −0.061c                  |
| Experience (Years)         | −0.067c                  | −0.068b                  | −0.062a                  |
| Family size (Number)       | −0.186c                  | −0.203b                  | −0.207a                  |
| Credit in PKR (x 10^5)     | 0.012                    | 0.031                    | 0.012                    |
| Extension agent visit      | −1.017a                  | −0.583c                  | −0.645a                  |
| Other occupation           | 1.122b                   | 0.764b                   | 0.103a                   |
| Certified seed             | −0.968a                  | −0.664c                  | −0.894a                  |
| Distance from Market (km)  | 0.730a                   | 0.251b                   | 0.382a                   |
| Off-farm income            | 0.897b                   | 0.804c                   | −0.0002                  |
| Tenancy                    | −0.779b                  | −0.767b                  | −0.511b                  |
| Television                 | −0.683c                  | −0.968c                  | −0.119                   |
| Livestock                  | −0.442                   | −0.080                   | −0.419                   |

Survey data, (2021). The a, b and c indicates the significance level at 1% and 5% respectively.

### TABLE 10 | GHG emissions from the manufacturing of urea and OLS.

| Variables                  | Top Dressing | Deep placement | Difference |
|----------------------------|--------------|----------------|------------|
| Total (MtCO2)              | 29.716       | 21.443         | 8.273      |
| Average (kgCO2)            | 237.72       | 171.54         | 66.18      |
| Standard deviation         | 158.36       | 117.58         |            |
| Minimum (kgCO2)            | 32.224       | 19.458         |            |
| Maximum (kgCO2)            | 687.24       | 513.91         |            |

### Direct GHG Emissions From Urea Fertilization

The use of synthetic N in the cropland emits GHG in the form of N2O–N. To convert the N to N2O, the estimated results are multiplied with the fraction 44/28. The results shown in able 11 display that the total fertilization of synthetic N applied to the maize crops by TD and DP respondents was 311.31 and 224.64 kgN2O. The projected result implies that TD respondents can reduce 86.67 kgN2O by shifting toward deep placement fertilization. Similarly, the average GHG emission due to the fertilization of synthetic N emits 2.49 and 1.80 kgN2O/ha. The difference between the two methods of fertilization shows that if the farmers used deep placement fertilization of synthetic N instead of top-dressing fertilization, the GHG emission can reduce by 0.12 kgN2O/ha. The estimated results are similar to the previous studies of Liu et al. (2006) and Signor et al. (2013), which stated that deep placement fertilization is the finest technique of mitigation of N2O soil emission. Correspondingly, Gaihre et al. (2016) stated that N2O emission from deep placement is 80% less than top dressing. The estimated results of OLS show that area and synthetic N have a significant impact on the manufacturing emission at a 1% significant level. An increase of 1 unit in area and synthetic N can increase the manufacturing emission by 1.14 and 0.03 kg of N2O.
TABLE 11 | Direct, OLS, yield, and area-scaled GHG emissions from synthetic N.

|                  | Top dressing | Deep placement | Difference |
|------------------|--------------|----------------|------------|
| Total (kgN\textsubscript{2}O) | 311.31       | 224.84         | 86.67      |
| Average (kg N\textsubscript{2}O/ha) | 2.49          | 1.80           | 0.69       |
| Standard deviation (kg N\textsubscript{2}O/ha) | 1.66          | 1.23           |            |
| Minimum (kg N\textsubscript{2}O/ha) | 0.36          | 0.20           |            |
| Maximum (kg N\textsubscript{2}O/ha) | 7.20          | 5.38           |            |

Ordinary Least Square for the manufacturing of Urea

|                  | Coeff (Std. Err) | Coeff (Std. Err) |
|------------------|------------------|------------------|
| Constant         | -2.39* (0.12)    | -1.79*(0.08)     |
| Area (hectare)   | 1.14* (0.04)     | 0.81* (0.03)     |
| Synthetic N (Kg) | 0.03* (0.001)    | 0.04* (0.001)    |

Yield-scaled GHG emissions from manufacturing and direct use of synthetic N

|                  | Total (KgCO\textsubscript{2}) | Average (KgCO\textsubscript{2}/Kg of grain) | Standard deviation (KgCO\textsubscript{2}/Kg of grain) | Minimum (KgCO\textsubscript{2}/Kg of grain) | Maximum (KgCO\textsubscript{2}/Kg of grain) |
|------------------|--------------------------------|---------------------------------------------|-------------------------------------------------------|---------------------------------------------|---------------------------------------------|
| Total (KgCO\textsubscript{2}) | 37.81                          | 21.95                                       | 15.88                                                 | 0.30                                        | 0.18                                        |
| Average (KgCO\textsubscript{2}/Kg of grain) | 0.30                          | 0.18                                        | 0.11                                                  | 0.06                                        | 0.03                                        |
| Standard deviation (KgCO\textsubscript{2}/Kg of grain) | 0.18                          | 0.11                                        | 0.03                                                  | 0.77                                        | 0.46                                        |

Area-scaled GHG emissions from manufacturing and direct use of synthetic N

|                  | Total (MtCO\textsubscript{2}) | Average (KgCO\textsubscript{2}/Ha) | Standard deviation (KgCO\textsubscript{2}/Ha) | Minimum (KgCO\textsubscript{2}/Ha) | Maximum(KgCO\textsubscript{2}/Ha) |
|------------------|--------------------------------|-------------------------------------|------------------------------------------|-----------------------------------|-----------------------------------|
| Total (MtCO\textsubscript{2}) | 53.41                          | 38.69                               | 14.72                                    | 117.79                            | 568.82                            |
| Average (KgCO\textsubscript{2}/Ha) | 427.30                         | 309.51                              | 117.79                                   | 117.79                            | 117.79                            |
| Standard deviation (KgCO\textsubscript{2}/Ha) | 167.06                         | 112.55                              | 117.79                                   | 117.79                            | 117.79                            |
| Minimum (KgCO\textsubscript{2}/Ha) | 176.34                         | 133.87                              | 117.79                                   | 117.79                            | 117.79                            |
| Maximum(KgCO\textsubscript{2}/Ha) | 708.18                         | 568.82                              | 117.79                                   | 117.79                            | 117.79                            |

Similarly, the study also measures the yield base GHG emission from the manufacturing and direct use of synthetic N in the respondent area. The projected results in Table 11 show that the area under TD and DP respondents emit a total of 37.81 and 21.95 kgCO\textsubscript{2} from the total grain produced. From the estimated results it is clear that 15.86 kgCO\textsubscript{2} can be reduced from the total yield produced by TD respondents. Likewise, the average GHG emissions from the manufacturing and direct use of N can be reduced by 0.12 kgCO\textsubscript{2} from 1 kg of maize grain. The average GHG emission from the TD and DP maize respondents was 0.30 and 0.18 kgCO\textsubscript{2}/kg of grain. Likewise, the area-based GHG emission from the manufacturing and direct use of N shows that the total GHG emission from the area used by TD and DP respondents was 53.41 and 38.69 MtCO\textsubscript{2}. The projected results show that TD respondents emit 14.72 MtCO\textsubscript{2} more than DP respondents. The average GHG emission from a single hectare of land for TD and DP was 427.30 and 309.51 kgCO\textsubscript{2}/ha. The result implies that TD respondents can reduce GHG emissions up to 117.79 kgCO\textsubscript{2}/ha by shifting from top-dressing fertilization to deep placement fertilization.

DISCUSSION

Farm profitability and productivity are the most important aim of farmers. Therefore, this study was carried out to differentiate the TD and DP fertilization methods based on their profitability, nitrogen efficiency, and greenhouse emission from the use of synthetic nitrogen (Urea). The study was based on primary data collected from different respondents and areas through a well-designed questionnaire. It is observed that the net revenue obtained from the top dressing was 71,187.8 PKR/ha while net revenue gained by side-dressing farmers was 172,087.2 PKR/ha. The profitability ratio portrays that the deep placement fertilization method was more profitable and least cost method as compared to the top-dressing fertilization. Similarly, by using the SFA model, the study also observed that the seed rate used by TD and DP groups are using quality seed of maize but the elasticity of seed for TD is more than DP, which implies that the seed quality and seedbed of TD is better than DP (Saddozai et al., 2015; Nasrullah et al., 2021a,b). Likewise, the number of labor used for TD and DP also shows a significant improvement in maize production. The significant impact of labor shows the better management, skill, and knowledge of labor used by the farmers (Ali et al., 2019; Jo et al., 2021).

The area used by the respondents in the study area shows that if the farmers increase their farmland can significantly improve productivity and efficiency. The farmer with more land pays more attention to farming. Zulfiqar et al. (2020a) and Nasrullah et al. (2019) stated that soil fertility and better management of land can increase production. Likewise, the irrigation application in the projected area is also significant for both TD and DP. The on-time irrigation can increase productivity while water stress can decrease the maize production.
and kernel size (Traore et al., 2000; Payero et al., 2009). The Farmyard manure also shows a substantial rise in production by providing micronutrients (Naveed et al., 2018). The DAP used by the respondents has significantly improved the maize yield (Chen et al., 2020). Similarly, the impact of urea is also statistically significant at a 1% significance level. The result indicates that an accurate amount of fertilizer was used at a suitable subsidized price (Ali et al., 2019). The tractor used for seedbed preparation has an effective impact on the production of maize in the study area. The machinery used for inverting and plowing land had a direct relation with production (Sekhon et al., 2010; Nasrullah et al., 2019). Likewise, pesticides used by respondents in the study area significantly improve maize production because pests and insects can reduce production (Popp et al., 2013).

The demographic, institutional, and socioeconomic factors are the important factors, which cannot be ignored when measuring the efficiency level of farmers. The inefficiency factor age has a significant impact on the efficiency level of maize growers in the TD or DP groups. The increase in age showed the weak physical condition of the growers (Saddozai et al., 2015). Similarly, the education level of maize growers shows that the improved skills of the farmers, which is a key indicator of achieving improved technology and getting maximum efficiency (Dhungana et al., 2004; Mariano et al., 2010) while Rios and Shively (2005) stated that higher education decreases the efficiency level.

Nitrogen is one of the key factors for maize growth, yield, and profitability (Khan et al., 2008). By considering the application rate of nitrogen by individuals, the GHG emission from the manufacturing of synthetic N consumed by top-dressing and deep placement fertilization was 29.716 and 21.443 MtCO₂... It is observed that carbon emissions of TD fertilization were more than that of DP fertilization. Similarly, the estimated results of OLS show that an increase of 1 unit in area and urea can increase the manufacturing emission by 108.70 and 1.50 kgCO₂. The use of synthetic N in the cropland emits GHG in the form of N₂O–N. To convert the N to N₂O the estimated results are multiplied with the fraction 44/28. The projected result implies that TD respondents produce more GHG emissions than deep placement fertilization. Liu et al. (2006) and Signor et al. (2013) stated that deep placement fertilization is the finest technique of mitigation of N₂O soil emission.

**CONCLUSIONS**

The study was based on primary data in which the data are collected from different respondents and different areas using the TD and DP fertilization method through a well-designed questionnaire. It is concluded from the study that the TD method is costly as compared to the DP fertilization technique. It is observed that the fertilizer used by TD is more as compared to the DP group. It implies that during TD fertilization, most of the fertilizers fall on the leaves of maize plants which causes the burning of leaves, and reduces the yield and efficiency of nitrogen used. Similarly, the profitability ratio shows that both TD and DP respondents are using almost the same amount of inputs except urea. The cost per hectare incurred by the TD groups is more than the DP groups. Similarly, the yield of the TD growers is 727.82 kg/ha more than that of TD respondents. Therefore, if the farmers of TD move toward DP, they can increase their profit up to 34.47 thousand rupees per hectare. The maximum likelihood estimation shows that all the variable inputs used by both groups significantly improved maize production. The efficiency score shows that the average efficiency level of TD and DP respondents are 87% and 90%. To reach the 90% efficiency level, the farmers of TD need to use deep placement fertilization. Correspondingly, the gap between the mean efficiency and maximum efficiency score of the TD and DP groups also shows that the farmers of TD and DP can increase their efficiency up to 12% and 9% by using the same inputs. The findings also concluded that the GHG emission from the manufacturing of synthetic N during TD fertilization is more than that of DP. Similarly, it is also clear that Yield and Area-Scaled GHG emissions from the direct use of synthetic N of TD are greater than that of the DP group. During the top-dressing fertilization, most of the fertilizer fall on surface land unwittingly which easily diffuses to N₂O–N as compared to the DP fertilization. This unwanted diffusion of synthetic N is not only harmful to the environment but also can increase the cost and decreases the yield of respondents.

Based on the study findings, it is suggested that

1) DP fertilization has a less harmful effect than TD fertilization on the environment. Therefore, special training and programs are needed for the farmers’ community to reduce GHG emissions.

2) All the inputs used by the respondents showed a significant impact on maize production. Therefore, for increasing the farmer’s yield, profit, efficiency, and food security, farmers need to use all the inputs in a better way to maximize their production.

3) Based on the efficiency score in the respondent area, the farmers need to adopt a new technique, seed quality, and seedbed to get maximum efficiency with the given level of inputs.

4) Based on the profitability ratio, farmers’ efficiency level, and GHG emissions, it is suggested that farmers need to prefer DP fertilization instead of TD to get maximum profit and yield with low environmental damage.

**DATA AVAILABILITY STATEMENT**

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

**AUTHOR CONTRIBUTIONS**

MN: conceptualization, formal analysis, investigation, and writing the original draft. MR: data collection and software. XY: methodology and formal analysis. LL: supervision, investigation, and data correction. AM, HA, BA, and SF: formal analysis,
methodology, and editing. All authors contributed to the article and approved the submitted version.

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