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Comparative Efficacy of Foliar Plus Soil Application of Urea versus Conventional Application Methods for Enhanced Growth, Yield, Agronomic Efficiency, and Economic Benefits in Rice

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ABSTRACT: The experiment was conducted at the research field, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur from December 2017 to May 2018 to find out the best treatment of foliar application of urea on the growth and yield of boro rice cv. BRRI dhan28. The experiment consisted of 10 treatments, laid out in a randomized complete block design in triplicate. The recommended doses (RD) of urea, TSP, MOP, gypsum, $ZnSO_4$, and borax were applied during land preparation except for urea at 250, 75, 100, 75, 7, and 5 kg ha^{-1}, respectively, where urea was applied as per treatment specification. The results revealed that the application of N fertilizer as foliage along with soil significantly influenced the growth, plant characteristics, and yield of BRRI dhan28. There was no significant difference between T_8 (70% in soil and 10% as foliage) and T_9 (100% in soil) treatment regarding the maximum panicle length (21.43 and 20.71 cm), fertile grains (117.40 and 113.30), total grains (134.40 and 130.97), 1000-grain weight (24.56 and 23.56 g), grain yield (5.91 and 5.74 t ha^{-1}), straw yield (7.83 and 7.92 t ha^{-1}), biological yield (13.74 and 13.66 t ha^{-1}), and harvest index (43.01 and 42.02%), respectively, in this study. These results indicated that N fertilization as direct soil application (70%) and as foliage application (10%), i.e., 80% N fertilization, produced the highest grain yield and major yield traits which we received by 100% N fertilization as soil that was practiced traditionally by the farmers. The effect of overfertilization (T_{10}) was not positive, producing the highest number of noneffective tillers and sterile grains (nonfilled grains). Therefore, it is possible to achieve an equivalent or more yield by saving 20% urea by the combination of soil (70%) and foliage (10%) application as compared to the traditional method of fertilizer application (100% in soil).

Treatments	GR (Tk ha^{-1}) 1	TVC (Tk ha^{-1}) 2	GM (Tk ha^{-1}) 3=(1-2)	MGM (Tk ha^{-1}) 4=(3-T1)	MBCR 5=(4/2)
T1 = (No urea)	55820	-	55820	-	-
$T_{50\%}N =_{2\ SA} + N_{10\%FA}$	81460	2700	78760	22940	8.50
$T_{50\%}N =_{3\ SA} + N_{15\%FA}$	87280	2925	84355	28535	9.76
$T_{50\%}N =_{4\ SA} + N_{20\%FA}$	88680	3150	85530	29710	9.43
$T_{60\%}N =_{5\ SA} + N_{10\%FA}$	89900	3150	86750	30930	9.82
$T_{60\%}N =_{6\ FA} + N_{15\%FA}$	100680	3375	97305	41485	12.29
$T_{60\%}N =_{7SA} + N_{20\%FA}$	112660	3600	109060	53240	14.79
$T_{70\%}N =_{8\ SA} + N_{10\%FA}$	118120	3600	114520	58700	16.31
$T_{100\%}N =_{9\ SA}$ (Traditioanal)	114800	4500	110300	54480	12.11
$T_{100\%}N =_{10\ SA} + N_{10\%FA}$	106020	4950	101070	45250	9.14

■ INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important cereal food grain crops of the world, grown in a wide range of climatic zones.[1] It is the staple food for nearly half of the world's population, most of whom live in developing countries.[2] Global population estimates have predicted the need for a 70% increase in rice production over the next 30 years.[3] Due to the constant increase in the world's population and adverse climatic conditions, rice production should be increased adequately to satisfy the demand for food for the growing population per year. Almost 90% of paddy is grown and consumed in Asia. Millions of people in Asia subsist entirely on rice, and over 90% of the world's rice is grown and eaten in Asia.[4] Rice is the staple food of about 160 million people in Bangladesh. This sector contributes half of the agricultural GDP and one-sixth of the national income in Bangladesh. It provides nearly 48% of rural employment, about two-thirds of the total calorie supply, and one-half of the total protein intake of an average person in the country.[4] It is the most extensively cultivated cereal crop in Bangladesh.

Rice dominates the cropping pattern throughout the country, as almost 80% of the cropped area is used for rice production, with an annual production of 35.55 million metric tons in the total acreage of 11.61 million ha. Boro rice is one of the major cereal food grains in Bangladesh, which is transplanted in the Rabi season (December to May). The productivity of boro rice depends on several climatic

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parameters, hydrological properties of soil, rice varieties, and major production inputs such as fertilizer management practices, irrigation, pests, and weed management.

The climatic and edaphic conditions of Bangladesh are favorable for rice cultivation throughout the year. The average yield of rice in Bangladesh is quite low (2.35 t ha^{-1}) compared to that in other leading rice-growing countries such as China (6.23 t ha^{-1}), Korea (6.59 t ha^{-1}), Japan (6.7 t ha^{-1}), and USA (7.04 t ha^{-1}).[5] On the other hand, the rice production area is decreasing day by day due to the high population pressure. Therefore, attempts should be made to increase the yield per unit area through the use of comparatively high-yielding varieties, along with proper and intensive fertilizer management and improved management practices.

Fertilizer is the most important nutrient element in soils and play the most vital role in crop production in Bangladesh. For maximizing the yield of rice, nitrogenous fertilizers are the kingpin in rice farming. Nitrogen can increase rice grain yield by increasing the total dry matter production, the number of panicles, and the panicle length of lowland rice.[6] The nitrogen use efficiency (NUE), in particular of urea fertilizer, is very low (30−35%) in the rice cropping system,[7] and the recovery of N in wetland rice seldom exceeds 40%.[8] Unfortunately, only 20−50% of the soil-applied N is recovered by the annual crops, indicating that more than 50% of the applied nitrogen is lost from the soil system through denitrification, volatilization, leaching, runoff, and so forth. This huge loss of N increases the fertilizer cost of farmers, decreases crop harvests, and sometimes causes environmental as well as groundwater pollution.[9] Both excess and insufficient nitrogen applications may cause either yield reduction or some physiological disorders like hollow stem and some pathological problems, leading to increased production costs and negative effects of blocking sustainable agricultural development.[10] More splitting of N produced a higher yield of rice due to the continuous supply of N.[11]

Many strategies have been developed to increase the efficiency of applied fertilizers through proper timing, deep placement, foliar application, modified forms of fertilizers, irrigation control, and so forth. Among them, the foliar application of urea introduces a new dimension to the nitrogenous fertilization regime. A foliar spray of nutrients bestows quicker and better results than the soil application, and currently, it is practiced in different crops.[11−17] Recently, foliar application of nutrients has become an important practice in the production of crops, while the application of fertilizers to the soil remains the basic method of feeding the majority of the crop plants.[18] The report states that the application of urea through foliar spray can reduce the requirement of urea fertilizer by 80% of soil application.[19] The foliar application of nitrogen was more effective than broadcast application alone; in such a situation, the foliar application of plant nutrients is effective and economical for some crops.[20] Several researchers have shown that foliar nitrogen application has a higher recovery than soil application.[11,17,18,21,22] However, it is still believed that soil nitrogen application cannot be completely substituted by foliar application[23] but can reduce the loss in yield due to the nonavailability of nitrogen. To fulfill the crop requirement, the combination of soil and foliar nitrogen application may be more efficient that reduces N losses.[18] In many cases, the aerial spray of nutrients is preferred which provided quicker and better results than soil application.[13] Therefore, it is essential to improve the fertilizer use efficiency, especially nitrogenous fertilizers, in rice under field conditions. A foliar spray of fertilizer not only increases crop yields but also reduces the quantity of fertilizer applied through the soil. Therefore, the present study was selected to study the effect of foliar application of urea on the growth, plant characteristics, yield, agronomic efficiency, and economic return of BRRI dhan28.

■ RESULTS AND DISCUSSION

Total Dry Matter. Nitrogen fertilization in soil and foliage significantly influenced the total dry matter (TDM) production of BRRI dhan28 at different growth stages (Table 1). The TDM increased with the increasing N fertilization in soil at both growth stages (60 and 75 DAT).

Table 1. Effect of Soil and Foliar Application of Urea on the TDM at 60 and 75 DAT of BRRI dhan28[a]

	total dry matter weight (g hill^{-1})	
treatments	60 DAT	75 DAT
T_1	24.65 d	31.45 c
T_2	26.77 c	35.67 bc
T_3	28.34 bc	36.65 b
T_4	30.29 b	36.98 b
T_5	30.81 b	37.66 b
T_6	30.91 b	38.57 b
T_7	31.93 ab	37.95 b
T_8	32.67 a	40.66 ab
T_9	33.56 a	42.23 a
T_{10}	34.95 a	45.46 a
LSD	1.35	2.01
CV (%)	5.34	9.54

[a]T_1 = N_0 urea, T_2 = $N_{50\%SA}$ + $N_{10\%FA}$, T_3 = $N_{50\%SA}$ + $N_{15\%FA}$, T_4 = $N_{50\%SA}$ + $N_{20\%FA}$, T_5 = $N_{60\%SA}$ + $N_{10\%FA}$, T_6 = $N_{60\%FA}$ + $N_{15\%FA}$, T_7= $N_{60\%SA}$ + $N_{20\%FA}$, T_8 = $N_{70\%SA}$ + $N_{10\%FA}$, T_9 = $N_{100\%SA}$, T_{10} = $N_{100\%SA}$ + $N_{10\%FA}$. Means followed by the same letters in a column are not statistically different at $p < 0.05$ according to the least significance difference (LSD) test.

The maximum values of TDM were recorded at T_{10} treatment (34.95 and 45.46 g) which was statistically of the same rank with T_9 and T_8 treatments, and the minimum (24.65 and 31.45 g) were recorded with T_1 treatment (without urea) at 60 and 75 DAT, respectively. Similar results were confirmed by the study of Gholami et al.,[21] wherein it was observed that 50% RDF (recommended dose of fertilizer) and three times foliar spraying of urea produced superior dry matter (increased by 4.44%) to 100% RDF in soil. It has been reported previously that the foliar feeding of N along with soil application significantly increased the dry matter production by superior vegetative growth over soil-applied N in wheat.[18] Foliar spraying of N along with soil application may ensure a nonstop supply of N that delayed the senescence of leaves, which in turn remained engaged in the production of photosynthates for a relatively long period, leading to higher TDM. It has been noticed that two times application of nitrogen at active tillering and panicle initiation stages increased the dry matter yield of rice over a single application.[24] Nitrogen fertilization at flowering and fruiting including seed formation and maturation might increase the TDM.[25] The higher TDM production may be attributed to the continuous supply of N through the soil and foliage, resulting in better plant height and total tillers after all initial plant

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Table 2. Effect of Soil and Foliar Application of Urea on the Yield-Contributing Traits of BRRI dhan28[a]

treatments	PH (cm)	ET $hill^{-1}$	NET $hill^{-1}$	PL (cm)	FG $panicle^{-1}$	NFG $panicle^{-1}$	TG $panicle^{-1}$	TSW (g)
T1	75.85 d	12.67 d	1.33 c	16.48 d	85.34 d	7.00 d	92.34 d	19.74 c
T2	85.62 c	13.23 c	1.67 bc	17.43 c	96.00 c	12.11 bc	108.11 c	21.40 b
T3	87.40 c	13.38 c	2.00 b	17.94 bc	97.23 c	13.00 b	110.23 c	22.40 ab
T4	88.45 c	14.67 c	2.67 b	19.40 ab	99.34 c	12.00 bc	111.34 c	22.62 ab
T5	89.07 bc	15.67 b	2.43 b	18.32 b	101.30 bc	12.67 b	113.97 c	22.86 ab
T6	90.68 b	18.00 a	2.67 b	18.33 b	102.00 b	15.33 b	117.33 c	23.42 a
T7	90.87 b	18.32 a	2.54 b	20.34 a	115.70 a	14.00 b	129.70 b	24.14 a
T8	92.54 b	18.67 a	2.67 b	21.43 a	119.40 a	12.00 bc	131.40 b	24.56 a
T9	100.60 a	16.67 b	6.34 a	20.71 a	113.30 a	17.67 a	130.97 b	23.56 a
T10	95.73 ab	17.00 a	7.87 a	19.97 a	116.00 a	24.33 a	140.33 a	22.42 ab
LSD	11.67	15.23	3.45	9.12	21.23	5.45	17.34	5.43
CV (%)	8.25	3.55	2.74	5.61	7.86	9.42	7.46	4.12

[a] $T_1 = N_0$ urea, $T_2 = N_{50\%SA} + N_{10\%FA}$, $T_3 = N_{50\%SA} + N_{15\%FA}$, $T_4 = N_{50\%SA} + N_{20\%FA}$, $T_5 = N_{60\%SA} + N_{10\%FA}$, $T_6 = N_{60\%FA} + N_{15\%FA}$, $T_7 = N_{60\%SA} + N_{20\%FA}$, $T_8 = N_{70\%SA} + N_{10\%FA}$, $T_9 = N_{100\%SA}$, $T_{10} = N_{100\%SA} + N_{10\%FA}$, PH: plant height, ET: effective tillers, NET: noneffective tillers, PL: panicle length, NFG: nonfilled grains, TG: total grains, TSW: 1000-grain weight. Means, followed by the same letters in a column are not statistically different at $p < 0.05$ according to the least significance difference (LSD) test.

stands, which eventually increased the TDM as these growth characteristics have a positive correlation with the TDM production. The findings in the present study are in line with those of other researchers around the world.[26−28]

Plant Characteristics. *Plant Height.* The plant height of BRRI dhan28 was significantly influenced by the soil and foliar application of urea. The plant height gradually increased with the increment of urea up to the 100% recommended dose (RD). However, the tallest plant (100.60 cm) was observed in the T_9 treatment, followed by the T_{10} treatment, while the lowest (75.85 cm) was in the T_1 treatment. The increment in plant height might be due to more and continuous availability of nitrogen through soil and foliar application over other treatments. Nitrogen is associated with an increase in protoplasm, cell division, and cell enlargement, resulting in taller plants.[29] It has been reported that plant height increased with an increase of N fertilization with two or three splits, while the grain yield increased with moderate N fertilization.[6] Three splits of N at transplanting (50%), tillering (25%), and panicle initiation stages (25%) gave a higher plant height than two equal splits at the transplanting and tillering stages or one time at transplanting.[13] The application of urea at three equal splits facilitated higher vegetative growth and hence attained the maximum plant height in aromatic rice.[15,16] Nitrogen is an essential constituent of chlorophyll and well-supplied nitrogen which enhanced the crop growth vigorously,[30] and both soil and foliar application of N significantly increased the plant height over soil-applied N in rice[17,20] and wheat.[26]

Number of Effective Tillers $hill^{-1}$. Different methods of nitrogen fertilization significantly influenced the number of effective tillers of BRRI dhan28 (Table 2). The number of effective tillers gradually increased with the increasing N fertilization, and both soil and foliar applications produced a higher number of effective tillers than the sole soil application. The highest number of effective tillers (18.67) was recorded in the T_8 treatment, which was statistically similar to the T_7, T_6, and T_{10} treatments, while the lowest (12.67) was in the T_1 treatment. The results of the present experiment agreed well with the findings of other researchers who concluded that foliar application of urea significantly increased the number of effective tillers $hill^{-1}$ of BRRI dhan29.[11−17] Foliar spraying of 3% urea solution produced a higher number of effective tillers $hill^{-1}$ than 1% urea spraying.[31] Soil (75%) and foliar (10%) application of urea significantly increased the effective tillers of Binahsail and BRRI dhan46 varieties during the T. aman season.[12] Many studies showed that the soil and foliar application of N increased the number of effective tillers $hill^{-1}$ in many crops.[13,32−34]

Number of Noneffective Tillers $hill^{-1}$. The number of noneffective tillers $hill^{-1}$ was significantly influenced by nitrogen fertilizer doses and application methods. The highest number of noneffective tillers $hill^{-1}$ (7.87) was observed from T_{10}, whereas the lowest (1.33) was observed from the T_1 treatment. The unavailability of nitrogen in rice might be the reason for producing the minimum noneffective tillers $hill^{-1}$ because the N status of the experimental plot was very low, below the critical level (Table 6). Higher doses of urea fertilization as soil and foliage may increase the secondary and tertiary tillers, which fail to produce panicles, resulting in the increase in the number of noneffective tillers $hill^{-1}$. The finding contrasts with the results of Al-Amin,[35] who obtained the minimum number of noneffective tillers $hill^{-1}$ from the foliar spraying of 3% urea solution, and the maximum was in 1.5% urea spraying. An insignificant variation in the production of noneffective tillers $hill^{-1}$ was found by Khanam[36] due to the effect of frequency of foliar application of urea solution.

Panicle Length (cm). A significant influence was observed on the panicle length due to the different nitrogen fertilizer doses and application methods of rice. The highest length of the panicle (21.43 cm) was obtained from T_8, and the smallest (16.48 cm) was recorded from the T_1 treatment. The result of the study is in agreement with that of Al-Amin[35] who obtained the longest panicle length from the foliar spray of 3% urea solution and the shortest one from 2% urea solution. Higher doses of N increased the panicle length per plant.[37] The longest panicle length was observed from 6 times foliar spray of urea solution.[38] Soil and foliar application of urea uninterrupted the supply of N which enhanced the plant growth (Table 2), which may be the reason for the increase in panicle length, which was supported by Islam et al.,[39] who reported that more splitting of N remarkably increased the panicle length.

Number of Filled Grains $Panicle^{-1}$. The number of filled grains $panicle^{-1}$ of rice was significantly influenced by the nitrogen fertilizer doses and application methods. However, the highest total number of filled grains $panicle^{-1}$ (117.40) was observed from T_8, and the lowest (85.34) was observed from T_1 treatment. The amount of TDM in the plant body, the optimum number of tillers, and pollination enhanced the number of filled grains panicle^{-1}. This result is in agreement with other researchers who reported that both soil application and foliar spraying of urea markedly increased the number of grains per panicle in rice.[13,32−34] In another study, Alam et al.[40] reported that the application of 33.33% urea as soil and 3% urea as foliar produced an equal number of grains per panicle in rice (BRRI dhan29) that was obtained at 100% soil-applied urea. Soil and foliar application of fertilizers also significantly increased the grains per spike of wheat.[37,38,41]

Number of Sterile Grains Panicle^{-1}. Nitrogen fertilizer doses and application methods showed significant effects on the unfilled grains panicle^{-1} of rice. The highest number of sterile grains panicle^{-1} (24.33) was obtained from the T_{10} treatment, and the lowest number (7.00) was observed from the T_1 treatment. The higher number of sterile grains panicle^{-1} may have occurred due to a lack of pollination, very low or overproduction of TDM in plants owing to N deficiency or overdose (Table 2), or an infestation of pests in rice. Foliar spraying of 2% urea solution produced the lowest number of sterile spikelets panicle^{-1}, whereas 1% urea solution-treated plants produced the highest number of sterile spikelets panicle^{-1}.[42]

Total Grains Panicle^{-1}. The total number of grains panicle^{-1} of rice was significantly influenced by the N fertilizer doses and application methods. Nonetheless, the highest number of grains panicle^{-1} (140.33) was observed from T_{10}, and the lowest (92.34) was observed from T_1. Soil and foliar application of N (75−80%) produced a higher number of total grains as compared to 100% soil-applied N through traditional methods. These results are consistent with the previously reported findings for rice, where the highest number of grains panicle^{-1} were obtained from foliar spraying of 2% urea solution.[10] In another study, it has been depicted that five times foliar spraying of urea @ 100 kg ha^{-1} significantly increased the number of grains panicle^{-1} in rice.[39,40] Both soil- and foliar-applied N significantly increased the grains per spike of wheat.[18,21]

Weight of 1000 Grains. The weight of 1000 grains was significantly influenced by the effect of nitrogen fertilizer doses and application methods. The highest and the lowest 1000-grain weights (24.56 and 19.74 g, respectively) were recorded from the T_8 and T_1 treatments, respectively. The 1000-grain weight increased up to the soil and foliar ($N_{80\%}$) application of N (T_8) over the control and thereafter decreased with 100% soil (T_9) and 110% soil (100%) and foliar (10%) application of N (T_{10}). The increment of grain weight at a higher nitrogen rate might be primarily due to an increase in the chlorophyll content of leaves, which leads to a higher photosynthetic rate, and ultimately plenty of photosynthates available during grain development.[30] Foliar application of urea at the later growth stages of the crop might have increased the availability of nitrogen to the crop, which probably has favored the enhanced accumulation of photosynthates (TDM; Table 1) in the grains. These results are in line with Gholami et al.,[21] who reported a significant increase in 1000-grain weight with the foliar application of nutrients. A significant increase in the 1000-grain weight with 2% foliar application of urea[26] and 3% urea solution[35] over the control treatment (N_0) is also reported.

Crop Harvests. *Grain Yield (t ha^{-1}).* Grain yield is the most important parameter in this study. The grain yield showed significant variation among the treatments of fertilizer doses and application methods (Table 3).

Table 3. Effect of Soil and Foliar Application of Urea on the Grain Yield, Straw Yield, Biological Yield (t ha^{-1}), and HI (%) of BRRI dhan28[a]

treatments	grain yield (t ha^{-1})	straw yield (t ha^{-1})	biological yield (t ha^{-1})	harvest index (%)
T_1	2.79 e	4.81 d	7.60 e	36.71 e
T_2	4.07 d	6.37 c	10.44 d	38.98 d
T_3	4.36 c	6.61 c	10.97 cd	39.74 c
T_4	4.43 c	6.81 c	11.24 c	39.41 c
T_5	4.49 c	6.83 c	11.32 c	39.66 c
T_6	5.03 b	7.19 b	12.22 b	41.16 b
T_7	5.63 ab	7.65 b	13.28 a	42.39 a
T_8	5.91 a	7.83 ab	13.74 a	43.01 a
T_9	5.74 a	7.92 ab	13.66 a	42.02 a
T_{10}	5.30 b	8.46 a	13.76 a	38.54 c
LSD	2.23	1.56	6.76	1.96
CV (%)	12.26	14.21	7.90	8.64

[a] $T_1 = N_0$ urea, $T_2 = N_{50\%SA} + N_{10\%FA}$, $T_3 = N_{50\%SA} + N_{15\%FA}$, $T_4 = N_{50\%SA} + N_{20\%FA}$, $T_5 = N_{60\%SA} + N_{10\%FA}$, $T_6 = N_{60\%FA} + N_{15\%FA}$, $T_7 = N_{60\%SA} + N_{20\%FA}$, $T_8 = N_{70\%SA} + N_{10\%FA}$, $T_9 = N_{100\%SA}$, $T_{10} = N_{100\%SA} + N_{10\%FA}$. Means, followed by the same letters in a column are not statistically different at $p < 0.05$ according to the least significance difference (LSD) test.

The highest grain yield (5.91 t ha^{-1}) was recorded in T_8 which was statistically similar to the T_9 treatment (5.74 t ha^{-1}) and the lowest yield (2.79 t ha^{-1}) in the T_1 treatment. The grain yield increased by 2.96% at T_8 (80% soil and foliar) over that at T_9 (100% soil-applied urea) in this observation (Table 4).

Table 4. Effect of Soil and Foliar Application of Urea on the Grain Yield Performance over Control and RDF (100% Urea as the Conventional Method)

treatments	grain yield (t ha^{-1})	increase (%) over control	change (%) over 100% urea
T_1 = (No urea)	2.79 e[a]		−51.39
$T_2 = N_{50\%SA} + N_{10\%FA}$	4.07 d	45.88	−29.09
$T_3 = N_{50\%SA} + N_{15\%FA}$	4.36 c	56.27	−24.04
$T_4 = N_{50\%SA} + N_{20\%FA}$	4.43 c	58.78	−22.82
$T_5 = N_{60\%SA} + N_{10\%FA}$	4.49 c	60.93	−21.78
$T_6 = N_{60\%FA} + N_{15\%FA}$	5.03 b	80.29	−12.37
$T_7 = N_{60\%SA} + N_{20\%FA}$	5.63 ab	101.79	−1.92
$T_8 = N_{70\%SA} + N_{10\%FA}$	5.91 a	111.83	2.96
$T_9 = N_{100\%SA}$	5.74 a	105.73	
$T_{10} = N_{100\%SA} + N_{10\%FA}$	5.30 b	89.96	−7.67

[a] Means, followed by the same letters in a column are not statistically different at $p < 0.05$ according to the least significance difference (LSD) test.

The findings are in agreement with those of other researchers who reported that the foliar application of N increased the grain yield over sole soil application.[6,11,18,21,26,28] The application of N in the soil, as well as foliage, significantly increased the grain yield as compared to the traditional method of application (100% in soil).[41] It has also been reported that foliar spraying of urea solution significantly increased the grain yield of rice.[43] Foliar feeding of urea in combination with soil application significantly increased the grain yield of other

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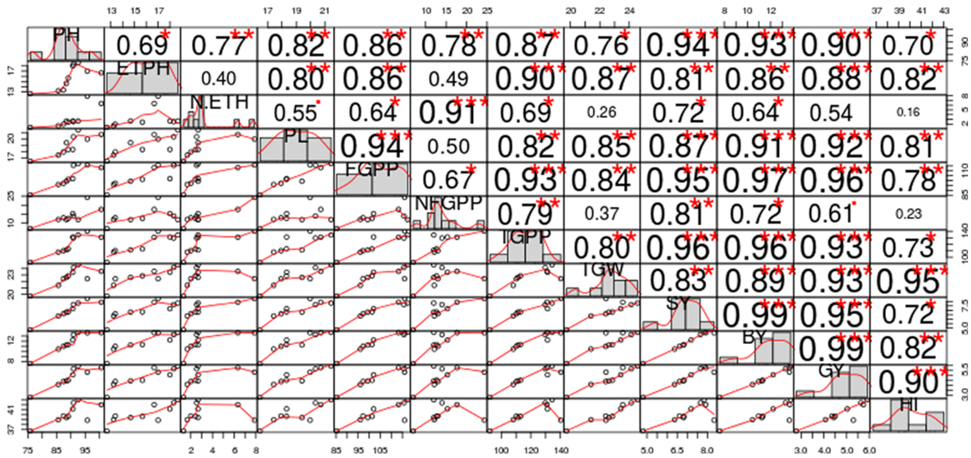

Figure 1. Association of different study traits from each other. Note: PH = plant height; ETPH= effective tillers per hill, NETH = noneffective tillers per hill, PL = penicle length; FGPP= filled grains per panicle, NFGPP= nonfilled grains per panicle, TGPP= total grains per panicle, TSW= thousand seed weight; SY= straw yield; BY= biological yield; GY= grain yield; HI= harvest index. *, **, and *** indicate statistical significance at $p < 0.05$, $p < 0.01$, and $p < 0.001$%, respectively.

crops.[26,28,43,44] Nitrogen can increase the grain yield of rice by increasing the vegetative growth (Table 1) and plant characteristics such as the number of effective tillers, panicle length, and filled grains panicle^{-1} (Table 2) in this observation. This result is consistent with the findings of de Datta and Buresh[8] on lowland rice. On the other hand, the plants treated with higher doses of N (110%) produced a considerably lower grain yield as compared to 100% soil (T_9) and 80% both soil and foliage (70% as soil and 10% as foliage) fertilization (T_8) in this study. The reason might be that a higher level of N is responsible for vigorous plant growth (Table 1), superior noneffective tillers hill^{-1}, and nonfilled grains panicle^{-1} (Table 2), consequently reducing the grain yield (−7.67%). Liquid fertilization with *Magic Growth* solution along with 75% of the recommended nitrogen fertilizer increased by 10.5% grain yield with a saving of 25% of the recommended nitrogen fertilizer compared to the recommended practice (100% in soil).[40] Our results are in line with the previous findings, which showed that the application of 80% urea (70% in soil and 10% on foliage at 40 and 50 DAT) produced an equivalent yield to that obtained with 100% urea (RDF) through the farmer's traditional practice of only soil application that ultimately resulted in the saving of 20% N.[42] Plants absorb and utilize nutrients rapidly through foliar fertilization, which can assist in correcting deficiencies or preventing nutrient shortages during critical growth stages, and this might be the reason for the higher growth and yield of rice at the T_8 treatment.

Straw Yield. The straw yield of rice was significantly influenced by the different levels of nitrogen fertilizer and methods of application. The highest straw yield (8.46 t ha^{-1}) was obtained from the T_{10} treatment, which was at par with the T_8 and T_9 treatments, and the lowest result (4.81 t ha^{-1}) was obtained from the T_1 treatment (without urea). A similar conclusion was also drawn by Alam et al.,[40] wherein only 33.33% urea of RD as soil and 3% as foliar spray produced the statistically equal but numerically higher straw yield over soil-applied 100% RD of urea. In another study, it was reported earlier that soil and foliar application of 75% urea of recommended dose (RD) significantly increased the straw yield (15.67%) as compared to 100% RD of soil-applied urea.[18] The highest grain and straw yield was obtained by Hossain[43] with increasing the frequency of foliar application of urea (6 times). The foliar application of urea solution @ 2% with soil application significantly increased the straw yield.[40,41] A similar conclusion was suggested by Jamal et al.,[13] where the foliar and soil application of urea significantly increased the grain and straw yield of wheat. An increase in the dose of N increased the straw yield, and these findings are in line with that of Alam et al.[40] Both soil and foliar application of urea increased the higher values of growth and plant characteristics viz. TDM, plant height, total tillers, and panicle length (Table 2) over only soil-applied urea, which might have enhanced the straw yield.

Biological Yield. Significant influence was observed on the biological yield due to nitrogen fertilizer quantities and their application protocols on rice. The highest biological yield (13.76 t ha^{-1}) was observed from the T_{10} treatment, which was a statistically similar rank with the treatments T_7, T_8, and T_9, and the lowest (7.6 t ha^{-1}) was observed from the T_1 treatment (Table 3). Nitrogen fertilization in overdose (T_{10}) contributed to the highest TDM (Table 1), resulting in the highest biological yield (Table 3). The result of the present findings validates the results of Kutman et al.,[32] who stated that both soil and foliar application of 75% urea produced a higher biological yield of boro rice as compared to 100% soil-applied urea. Only 50% urea applied as soil and foliage showed a higher biological yield of boro rice (BRRI dhan29) over 100% soil-applied urea.[42] These data are in agreement with another study depicting the increased grain and straw yields (biological yield) of wheat radically with the soil and foliar application of urea as compared to the soil-applied urea.[35] The biological yield of rice was positively correlated with the grain yield.[43] The finding contrasts with the finding of Al-Amin[35] who obtained the highest biological yield (11.62 t ha^{-1}) in BRRI dhan29 from five times foliar application of 2% urea solution.

Harvest Index. Nitrogen fertilizer doses and application methods exhibited significant differences in the harvest index (HI) in rice. The highest HI (43.01%) was obtained from T_8, which was statistically similar to that from T_7 and T_9, and the lowest HI (36.71%) was recorded from the T_1 treatment. Plants grown without N (T_1) showed the minimum vegetative growth in rice; consequently, treatment T_1 showed the lowest HI than other treatments. N is the key element for rice growth, but the soil was deficient to N (Table 1), and the growth as

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Table 5. Agronomic Efficiency of Fertilizer by Foliar Spray in a Raised Bed and Fertilizer Broadcasting in Conventional Planting[a]

method of fertilizer application treatments	GYNA (kg ha^{-1})	GYNO (kg ha^{-1})	NR (kg ha^{-1})	AE of fertilizer (kg grains kg^{-1}urea)
T_1 = (no urea)	2791	2791	0	
$T_2 = N_{50\%SA} + N_{10\%FA}$	4073		150	8.55 d
$T_3 = N_{50\%SA} + N_{15\%FA}$	4364		162.5	9.68 c
$T_4 = N_{50\%SA} + N_{20\%FA}$	4434		175	9.39 c
$T_5 = N_{60\%SA} + N_{10\%FA}$	4495		175	9.74 c
$T_6 = N_{60\%FA} + N_{15\%FA}$	5034		187.5	11.96 b
$T_7 = N_{60\%SA} + N_{20\%FA}$	5633		200	14.21 a
$T_8 = N_{70\%SA} + N_{10\%FA}$	5906		200	15.58 a
$T_9 = N_{100\%SA}$	5740		250	11.80 b
$T_{10} = N_{100\%SA} + N_{10\%FA}$	5301		275	9.15 c
LSD				1.35
CV (%)				5.21

[a]GYNA= grain yield (kg ha^{-1}) with the addition of nutrient, GYN0= grain yield (kg ha^{-1}) without the addition of nutrient, NR= rate of added nutrient (kg ha^{-1}).

Table 6. Economic Analysis of Soil and Foliar Application of Urea BRRI dhan29 Production[a]

treatments	GR (Tk ha^{-1}) 1	TVC (Tk ha^{-1}) 2	GM (Tk ha^{-1}) 3 = (1−2)	MGM (Tk ha^{-1}) 4 = (3-T1)	MBCR 5 = (4/2)
T1 = (no urea)	55820		55820		
$T_2 = N_{50\%SA} + N_{10\%FA}$	81460	3900	77560	21740	5.57
$T_3 = N_{50\%SA} + N_{15\%FA}$	87280	4725	82555	26735	5.66
$T_4 = N_{50\%SA} + N_{20\%FA}$	88680	4950	83730	27910	5.64
$T_5 = N_{60\%SA} + N_{10\%FA}$	89900	4350	85550	29730	6.83
$T_6 = N_{60\%FA} + N_{15\%FA}$	100680	5175	95505	39685	7.67
$T_7 = N_{60\%SA} + N_{20\%FA}$	112660	5400	107260	51440	9.53
$T_8 = N_{70\%SA} + N_{10\%FA}$	118120	4800	113320	57500	11.98
$T_9 = N_{100\%SA}$ (traditioanal)	114800	4800	110000	54180	11.29
$T_{10} = N_{100\%SA} + N_{10\%FA}$	106020	6450	99570	43750	6.78

[a]GR: gross return, TVC: total variable cost; GM: gross margin, MGM: marginal gross margin, MBCR: marginal benefit−cost ratio, urea fertilizer @ 18 Tk kg^{-1}, rice @ 20.0 Tk kg^{-1}, and labor @ 300 Tk day^{-1}.

well as all plant characters showed the lowest values, consequently showing the lowest HI. The result is parallel to that of Hossain.[43] It has been reported that the foliar application of urea solution at different concentrations increased the HI.[35] Four times spraying of 2% urea solution produced higher HI than that of 1% urea solution.[13] On the other hand, three times foliar spraying of urea solution showed superior HI to five times foliar spraying of urea solution.[12]

Correlation among Different Traits. The PH showed a significant positive relationship with all of the study traits, whereas a strong correlation was found with the SY, BY, and GY (Figure 1). A similar result was found in the case of the FGPP and TGPP traits. The ETPH exhibited a nonsignificant relationship with NETH and NFGPP, but a significant positive relationship was shown with the rest of the study traits. The NETH gave a positive significant relationship with the BY, FGPP, NFGPP, TGPP, SY, and ETPH while exhibiting a nonsignificant relationship with the NETH, PL, HI, GY, and TGW. The panicle length (PL) showed a positive significant relationship with almost all the traits except with the NETH and NFGPP. The NFGPP showed a positive significant correlation with the PH, NETH, FGPP, BY, SY, and TGPP and at the same time exhibited nonsignificant correlation with the ETPH, PL, TGW, GY, and HI. Positive significant correlations were found between the TGW and other characters except for NFGPP and NETH. The SY showed a significant positive correlation with all the study traits, whereas a strong correlation was found with the PH, PL, FGPP, TGPP, BY, and GY. The BY also exhibited a significant positive correlation with all the study traits, whereas except for NETH, NFGPP, and HI traits, rest of the parameters found a strong correlation with the BY. The GY showed a positive nonsignificant effect with the NFGPP and NETH, while a strong significant positive correlation was found with the rest of the traits. Likewise, the HI showed a positive nonsignificant effect with the NETH and NFGPP, whereas a significant positive correlation was found with the rest of the traits in which the GY and TGW exhibited a strong correlation with the HI. The result means that the GY and TGW contribute more to the HI. The PL, TGPP, and SY were positively correlated with the GY, and the relationship was statistically significant when BRRI dhan29 was grown in different levels of soil and foliar application of urea.[13,32−34]

Agronomic Efficiency (AE). Agronomic efficiency (AE) is an important measure that determines the vehemence of certain inputs on a per unit basis in quantitative terms.[45] The AE is a yield-dependent parameter that is achieved by the yield gained over the control per unit of added input (fertilizer). As clear from Table 5, the application of N as soil and foliar spraying (80%) significantly increased the AE over the conventional method of N application (100% soil-applied). However, the highest AE (15.58%) was recorded at the T_8 treatment, which was treated with 70% urea as soil (12 and 25 DAT) and 10% foliar spray (40 and 50 DAT), and the AE of T_8 was statistically identical (14.21%) with the T_7 treatment (60% urea as soil at 10 and 25 DAT, and 20% as foliar spray at

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40, 50, and 60 DAT). Overdoses of urea (110%) in both soil and foliar spray (T_{10}) did not show satisfactory results. Higher AE at T_8 and T_7 treatments might be due to the higher and continuous uptake of N during the crop development stage, which promotes crop growth and yield and translocates more photoassimilates toward the grain. Unlike the study of Alam et al.,[42] who reported that both soil and foliar application of urea with reduced rate increased the N use efficiency (NUE) over the conventional method as prilled urea in boro rice (BRRI dhan29), our results are partially supported by Singh et al.,[44] who reported that the AE of foliar nitrogen fertilizer application in transplanted rice was higher than that of the conventional method. Urea solution spraying at different growth stages increased the AE/NUE/N apparent recovery in other crops.[11−18] Higher AE/NUE/N apparent recovery indicates that the foliar application of N minimizes the loss of N that results in an increased grain yield of rice (Tables 3 and 4) as compared to the broadcast application of N in the form of prilled urea (conventional method). Plants rapidly absorb and utilize nutrients through foliar fertilization.[11]

Economic Performance. The economic performance of soil and foliar application of urea fertilizer with the conventional method (only soil-applied) was evaluated in this study (Table 6). The outcome revealed that both soil and foliar applications of urea at different growth stages with reduced rates showed superior performance regarding gross return (GR), gross margin (GM), marginal gross margin (MGM), and marginal benefit−cost ratio (MBCR) to the usual urea fertilization (T_9) or overdoses with soil and foliar application (T_{10}). However, the highest values of GR (Tk. 118120), GM (Tk. 113320), and MGM (Tk. 57500) were recorded at T_8 treatment where 70% urea was applied as the conventional method and 10% of RD was applied as foliar spraying (5% + 5%). The highest MBCR of 11.98 was also recorded at the T_8 treatment, followed by the T_7 treatment (14.29). Soil and foliar application of 75% urea fertilizer (60 and 15%, respectively) showed a slightly higher value of MBCR (9.53) than the traditional method of urea fertilization (11.29), indicating that both soil and foliar application of urea fertilizer can save 30% urea in producing an equivalent yield by the traditional method. Treatment T_8 gave higher yield and economic values than treatment T_9, and the T_8 treatment showed the maximum MBCR. From the above discussion, we can say that treatment T_8 is the best in terms of obtaining higher grain yield from an economic point of view. These results are consistent with previously reported findings for rice, where 50% prilled urea + 5 foliar spray @ 0.5% N solution @ 5.5 kg N spray^{-1} showed the highest gross return, gross margin, and marginal gross margin.[43] The maximum benefit: cost ratio with soil and foliar application of N has been observed.[23] Our results are certified by Alam et al.[42] who reported that foliar fertilizers are likely to be cost-effective if the price of foliar products is no more than 15% greater than traditional fertilizers.

■ CONCLUSIONS

The present study investigated the impact of soil and foliar application of urea on the growth, plant characteristics, yield, agronomic efficiency, and economic return of BRRI dhan28. Application of urea fertilizer in soil along with that on plant foliage positively influenced the growth, yield-contributing traits, and yield of rice (BRRI dhan28). Most of the parameters showed significant differences among the treatments. Application of urea in soil (70%) and on foliage (10% at 40 and 50 DAT), i.e., T_8 treatment showed the highest values of TDM (32.36 and 40.66 g hill^{-1} at 60 and 75 DAT, respectively), effective tillers (8.67), panicle length (21.43 cm), filled grains (119.40 g panicle^{-1}), TSW (24.56 g), grain yield (5.91 t ha^{-1}), biological yield (13.74 t ha^{-1}), and harvest index (43.01%), as compared to all other treatments, and the values of those traits (except effective tillers) are statistically equivalent to the T_9 treatment that received 100% urea in soil (traditional method). Plants grown without urea (T_1) demonstrated the minimum values of growth, yield-contributing traits, and grain yield (2.79 t ha^{-1}). On the other hand, overdoses of urea (110%-T_{10}) in both soil and foliage-applied plants produced the highest values of the number of noneffective tillers hill^{-1} (7.87) and sterile grains panicle^{-1} (24.33), indicating that overdoses of urea should be avoided. The treatment combination of T_8 showed the best result, including the grain yield similar to that of T_9 treatment by saving 20% urea, and hence, foliar spraying of urea is a new technique that can be practiced for rice cultivation. The above arguments allowed the development of a hypothesis that foliar fertilizer spraying is a supplement to the soil application of the urea fertilizer, which has a significant impact on the crop yield, nutrient utilization efficiency, and economic aspects.

■ METHODS AND MATERIALS

Location and Experimental Site. The experiment was carried out at the Agronomy Research Field, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur. The geographical location of the site is between 25°13′ latitude and 88°23′ longitude and about 37.5 m above sea level. The experimental plot was in a medium−high land belonging to the Old Himalayan Piedmont Plain area (AEZ −1).

Soil Conditions. The experimental plot was in medium−high land belonging to the Old Himalayan Piedmont Plain area (AEZ-1) comprising sandy loam texture with pH 5.41. The initial soil (0−15 cm depth) test revealed that the soil contained organic matter (1.48%), total nitrogen (0.08%), available phosphorus (11.20 ppm), available potassium (0.10 mequiv 100 g^{-1}), available sulfur (17.29 ppm), and boron (0.13 ppm). The characteristics of the tested soil are presented in Table 7.

Climatic Conditions. The experimental site is under subtropical climate with usually high temperature, high humidity, and heavy rainfall (above 80% of the total rainfall) with occasional gusty winds. Weather data regarding rainfall, relative humidity, and sunshine hours prevailing at the site during the study period are presented in Figure 2.

Experimental Treatments and Design. The experiment consisted of 10 treatments viz. T_1 (N_0 urea) = control (no urea used) other fertilizers applied during final land preparation; T_2 ($N_{50\%SA}$ + $N_{10\%FA}$) = 20% urea at 10 DAT and 30% at 25 DAT as soil-applied (SA), + 5% urea at 40 DAT and 5% at 50 DAT as foliar-applied (FA); T_3 ($N_{50\%SA}$ + $N_{15\%FA}$) = 20% urea at 10 DAT and 30% at 25 DAT applied as SA, + 5% urea each at 40, 50, and 60 DAT as FA; T_4 ($N_{50\%SA}$ + $N_{20\%FA}$) = 20% urea at 10 DAT and 30% at 25 DAT as SA, + 6.66% urea each at 40, 50, and 60 DAT as FA; T_5 ($N_{60\%SA}$ + $N_{10\%FA}$) = 25% urea at 10 DAT and 35% at 25 DAT as SA, + 5% urea each at 40, and 50 DAT as FA; T_6 ($N_{60\%FA}$ + $N_{15\%FA}$) = 25% urea at 10 DAT and 35% at 25 DAT as SA, + 5% urea each at 40, 50, and 60 DAT as FA; T_7 ($N_{60\%SA}$ + $N_{20\%FA}$) = 25% urea at 10 DAT and 35% at 25 DAT as SA, + 6.66% urea each at 40, 50, and 60 DAT as

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Table 7. Chemical Properties of Experimental Soil with Critical Value and Extraction Methods

properties	value	critical value	methods used
soil pH (1:1.25, Soil:H_2O)	5.41		glass electrode pH meter[46]
organic matter (%)	1.48		wet oxidation method[47] calculated by Van Bemmelen factor 1.73[48]
N (%)	0.08	0.12	micro-Kjeldahl method[49]
available P (ppm)	11.20	10.00	molybdate blue ascorbic acid method[50]
exchangeable K (mequiv 100 g^{-1})	0.10	0.12	determined by a flame photometer
exchangeable Ca (mequiv 100 g^{-1})	2.48	2.00	atomic absorption spectrophotometer[51]
exchangeable Mg (mequiv 100 g^{-1})	0.29	0.50	extractable method[52]
available S (ppm)	17.29	10.00	turbidity method using $BaCl_2$[53]
available B (ppm)	0.13	0.20	monocalcium biphosphate method, determined by spectrophotometer following the azomethine H method[46]
available Zn (ppm)	0.90	0.60	AAS[54]
available Fe (ppm)	51.90	4.0	AAS[54]
available Mn (ppm)	12.13	1.0	AAS[54]
CEC (mequiv 100 g^{-1} soil)	5.7		sodium acetate saturation method[55]

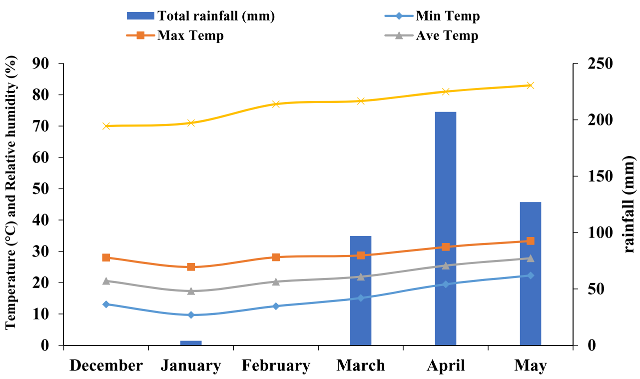

Figure 2. Monthly average temperature (minimum, maximum, and mean), relative humidity (%), and rainfall (mm) during the experiment.

FA; T_8 ($N_{70\%SA}$ + $N_{10\%FA}$) = 30% urea at 10 DAT and 40% at 25 DAT as SA, + 5% urea each at 40, and 50 DAT as foliar (FA); T_9 ($N_{100\%SA}$) = traditional method, i.e., 100% as SA (33.33% urea at 10 DAT, 33.33% at 25 DAT, and 33.33% at 40 DAT) and T_{10} ($N_{100\%SA}$ + $N_{10\%FA}$) = traditional method, i.e., 100% as SA (33.33% urea at 10 DAT, 33.33% at 25 DAT, and 33.33% at 40 DAT as SA), 5% urea at 40 and 5% 60 DAT as FA.

Experimental Design. The experiment was carried out in a randomized complete block design (RCBD). There were 10 treatment combinations, and each treatment was replicated three times. The treatments were randomly distributed on the plots within a block. Thus, the number of plots was 3 × 10 = 30. The unit plot size was 4.0 m × 2.5 m = 10 m^2, and an irrigation channel was made by 50 cm surrounding the individual plot.

Varietal Description. BRRI dhan28 was used as the test variety in the study. It is one of the important boro rice cultivars developed by the Bangladesh Rice Research Institute (BRRI) in 1994. It attained a height of 90 cm and a grain yield of 6 t ha^{-1}. It is a well-adapted variety to our climatic conditions, and its field performance is excellent after a long time of cultivation.

Production Technology. Healthy and vigorous seeds of BRRI dhan28 were collected from the Bangladesh Agriculture Development Corporation (BADC), Dinajpur. Healthy seeds were selected by the specific gravity method by immersing them in a bucket for 24 h. Then, the seeds were taken out of the water and kept in a thick gunny bag. The seeds were soaked in water and kept for 48 h at moist conditions for sprouting, and then the sprouted seeds were sown in the nursery bed. The seedling nursery was prepared by puddles in the soil. Weeds and stubble were removed, and the land was leveled properly. Sprouted seeds were sown in a broadcast method in the wet nursery bed on 10 December 2019. Proper care was taken to raise good seedlings in the seedbed. Weeds were removed from the seedbed, and the seedbed was always kept in moist conditions by applying irrigation.

The experimental land was first opened with a power tiller in January 2020. The land was submerged with enough water and thoroughly prepared with the help of a plow and ladder. This condition was kept for 2 days with sufficient water. Weeds and stubble were removed from the field. The bunds around individual plots were made for proper water management between the plots. The individual plots of each block were prepared thoroughly by spading and then leveled just before the specified date of transplanting on 25 January 2020. The field was fertilized with triple superphosphate, muriate of potash, gypsum, and zinc sulfate @ 250, 75, 60, and 7 kg ha^{-1}, respectively.[56] The whole amount of triple superphosphate, muriate of potash, gypsum, and zinc sulfate was applied at the final land preparation. The recommended dose of urea was applied in the soil at 10 and 25 days after transplantation (DAT). Foliar application of urea was applied as recommended at 40, 50, and 60 DAT. 45 day old seedlings were uprooted carefully from the nursery bed and transplanted in individual plots on January 25, 2020 at the rate of three seedlings $hill^{-1}$ with a spacing of 20 × 15 cm.

Intensive care was taken during the growing period for the proper growth and development of the rice crop. The following intercultural operations were done. Seedlings in some hills died off, and those were replaced by gap-filling after 7 days of transplanting with seedlings from the same source. Three-hand weeding was done during the entire growth period. The weeding was done at 20 and 45 DAT. The crop was found to be infested with a brown plant hopper (BPH) and was successfully controlled by spraying Sumithion 50EC @ 1.5 L ha^{-1} twice for the entire growing period at 35 and 55 DAT. Virtako 40 WG was applied for controlling yellow rice stem borer at 40 DAT, and before the booting stage of rice at @ 30g per acre Super Mac (Green Bangle Agroovet Ltd.) was applied two times at 60 DAT and after the panicle initiation stage at @ 10g per 33 decimals.

The crop was harvested at full maturity. The date of harvesting was confirmed when 90% of the grain turned golden yellow. Harvesting was done on 27 April, 2019. Five hills (excluding border hills) were selected randomly from each plot and uprooted before harvesting for recording data. After sampling, the whole plot was harvested. The harvested crop of each plot was separately bundled, properly tagged, and then brought to the threshing floor. The harvested crops were threshed manually. The grains were cleaned and dried to a

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moisture content of 12%. Straws were sun-dried properly. The final grain and straw yields plot^{-1} were recorded and converted to t ha^{-1}.

Data Collection. Data on the yield and yield-contributing characters were recorded from five randomly selected sample hills from each plot using the following parameters: dry matter, plant height, effective tillers hill^{-1}, noneffective tillers hill^{-1}, panicle length, number of total grains panicle^{-1}, number of fertile grains panicle^{-1}, number of nonfertile grains (sterile) panicle^{-1}, the weight of 1000-grains, grain yield, straw yield, biological yield, and harvest index (%).

Agronomic Efficiency (AE): The calculation of AE was done by using the following formulas developed by Shah et al.[57]

$$\mathrm{AEofNfertilizer(AE)} = \mathrm{GYNA} - \mathrm{GYN0/NR}$$

where GYNA = grain yield (kg ha^{-1}) with the addition of nutrient,

GYN0 = grain yield (kg ha^{-1}) without the addition of nutrients,

NR = rate of added nutrients (kg ha^{-1}).

Economic Analysis. A partial budget analysis was performed to calculate the changes of benefit for a proposed change in the farm input and operation. It is useful to think of partial budgeting as a type of marginal analysis as it is best adapted to analyzing relatively small changes in the whole farm plan.[58] SA was done two times from T_2 to T_{10}, and an extra one time only in T_9 and T_{10} treatments. FA was done 2, 3, 3, 2, 3, 3, 2, and 2 times at T_2, T_3, T_4, T_5, T_6, T_7, T_8, and T_{10}, respectively. One additional labor/ha was required in the T_9 and T_{10} for SA (split application), and two labors/ha were required at each time of FA. Application costs (soil vs soil + foliage) were considered with the variable cost.

To compare the different treatment combinations with one control treatment, the following equation was applied

$$\mathrm{MBCRovercontrol} = \frac{\mathrm{Grossreturn(T_i)} - \mathrm{Grossreturn(T_0)}}{\mathrm{VC(T_i)} - \mathrm{VC(T_0)}}$$

where Ti = T_2, T_3... T_9, T_{10}

T_0 = control treatment

VC = variable cost

Gross return = yield × price

Statistical Analysis. All the collected data were analyzed following the analysis of variance (ANOVA) technique by using the MSTAT-C program, and mean differences were adjudged by Duncan's multiple range test (DMRT).[59]

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