



# Nitrogen Use Efficiency of Low Land Rice as Affected by Organic and Chemical Sources

Amina Khatun<sup>1\*</sup>, Hasina Sultana<sup>1</sup>, Md. Sultan Uddin Bhuiya<sup>2</sup>, Md. Abu Saleque<sup>3</sup>

<sup>1</sup>Rice Farming Systems Division, Bangladesh Rice Research Institute, Gazipur, Bangladesh

<sup>2</sup>Department of Agronomy, Bangladesh Agricultural University, Mymensingh, Bangladesh

<sup>3</sup>Advanced Studies & Research, Bangladesh Rice Research Institute, Gazipur, Bangladesh

Email: [aminabrri@gmail.com](mailto:aminabrri@gmail.com)

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## Abstract

Given the increasing dairy and poultry industries, cowdung (CD) and poultry manure (PM) might become alternative sources of nitrogen (N) for rice production in South Asia. A field experiment was conducted during dry season (November-April) in Gazipur, Bangladesh. The experiment aimed to evaluate N use efficiency (NUE) in rice under varying sources of N application. Six treatments—1) N-control; 2) optimum dose of nitrogen (164 kg N ha<sup>-1</sup>) from urea; 3) 50% N from urea and 50% N from CD; 4) 50% N from urea and 50% N from PM; 5) 100% N from CD; and 6) 100% N from PM—were compared. Two mega varieties—BRRI dhan28 and BRRI dhan29—were used as test crops. In BRRI dhan28, the urea treatment had the highest agronomic use efficiency (AUE), utilization efficiency (UE) and partial factor productivity (PFP) followed by urea + PM treatment and absolute PM treatment. In BRRI dhan29, the urea + PM treatment had the highest AUE followed by absolute urea treatment while the urea + PM treatment gave the highest UE and PFP followed by urea treatment and urea + CD treatment. The absolute PM treatment gave the highest physiological efficiency (PE) followed by absolute urea treatment in BRRI dhan28. In BRRI dhan29, the absolute PM treatment had the highest PE followed by urea treatment and urea + PM treatment. The absolute PM treatment had the highest agro physiological efficiency (APE) both in BRRI dhan28 and BRRI dhan29. Based on this finding, it is concluded that the practice of integrated use of organic and chemical fertilizer has the scope to reduce chemical fertilizer and also contribute to increasing nitrogen use efficiency.

## Keywords

Rice, Cowdung, Poultry Manure, Urea, N Use Efficiency

**Subject Areas:** Agricultural Science

\*Corresponding author.

## 1. Introduction

Nitrogen is one of the most yield-limiting nutrients in rice production around the world [1], especially in tropical Asian soils and almost every farmer has to apply the costly N fertilizer to get a desirable yield of rice [2]. Judicious and proper use of fertilizers can markedly increase the yield and improve the quality of rice [3]. However, both excess and insufficient supply of nitrogen is harmful to the rice crop and may decrease grain yield. An adequate nitrogen supply can increase as much as 60% rice production over control [4].

Worldwide, N recovery efficiency for cereal production is approximately 33%. For lowland rice in the tropics, recovery efficiency is 30% - 50% of applied N depending on season, yield level, the rate and timing of N application [5] [6]. Low recovery of N fertilizer not only increases cost of production and but also may contribute to ground water pollution [7]. So, improved N fertilizer practices are needed to reduce environmental impacts and increase economic benefits of N fertilization.

Increasing cropping intensity with modern rice varieties has enhanced nutrient mining from the soil because nutrient removal has exceeded annual replacement, even if the national recommended fertilizer doses are applied. Moreover, farmers in Bangladesh are mainly concerned about the application of N fertilizer and tend to neglect P and K fertilizers for rice cultivation because their application often does not produce the yield advantages of the past [2]. Such imbalanced nutrient management practices may impair productivity of the soils of Bangladesh, which contain low levels of organic matter. In spite of balanced inputs N, P and K fertilizers, yield declines in India, particularly in treatments which received no P and K as compared to treatments that received balanced fertilizers [8].

Organic manures and chemical fertilizers are both important for rice cultivation. Organic manures improve the physical condition of the soil and supply limited quantities of plant nutrients through enhanced microbial activity [9]. Fertilizers, on the other hand, contain one or more plant nutrients in concentrated readily available forms. They can be so applied as to supply the nutrients needed by plants and thereby increase crop growth and yield [9].

Sustainability in crop yield and soil health could be achieved by the application of mineral fertilizers along with organic manures. Benefits of organic manures like farm yard manure, green manures, poultry manure and vermicompost are well-known but the availability is reducing day by day. These organic manures not only are good sources of nutrients but also improve the physical structure of the soil. Apart from containing NPK, these also contain small amounts of trace elements especially boron, copper, iron, sulphur, zinc and with fair quantity of growth promoting substances. Integrated nutrient management involving both the organic and inorganic source is, imperatively, essential to realize higher yield potential.

Integrated nutrient management—the combined use of chemical fertilizers and organic amendments—can be a measure to maintain sustainable soil productivity in tropical countries such as Bangladesh. It is well recognized that soil organic matter is an important fertility parameter, which largely determines soil quality. The average organic matter content of Bangladesh soil is about 1.0%. Under tropical climates increasing organic matter to a high level is not possible [2].

Cow dung is a good source of different plant nutrients particularly NPKS and judicious application of cow dung along with inorganic nutrients might be helpful to obtain a good economic return as well as provided favorable conditions for subsequent crops [10]. The application of cowdung in rice fields may reduce the requirement of chemical fertilizers. The doses of chemical fertilizer may be reduced by 33% for both dry and wet season by using cowdung and ash in the dry season [2]. The application of cowdung and ash not only supplemented chemical fertilizers but also contributed to the apparent nutrient balance [2].

Poultry manure is an excellent source of promising organic fertilizer, which is cost effective to the farmers. Nowadays, industrialization of poultry is a vital sector of national economy in Bangladesh and byproduct of this industry, *i.e.*, manure and poultry liter may be used as good source of organic matter with a view to develop an agronomically and economically suitable combination of organic and inorganic fertilizers for improving soil health and rice production. It has a high nutritional value for plant growth [11] [12]. Management of animal wastes from animal confinement facilities is a very important issue in swine and poultry farming. If inadequately handled, animal manure poses a significant threat to the quality of air and water nearby the storage and disposal areas. When properly managed, animal manure is a valuable source of fertilizer for crop production [13]. Under these circumstances, the present study was designed to evaluate the N use efficiency of rice under organic and chemical sources.

## 2. Materials and Methods

The field experiment was conducted at the experimental farm of the Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh, located at 23°59'N latitude, 90°24'E longitude. The site is about 35 m above the mean sea level and has a subtropical climate, which is strongly influenced by the southwestern monsoon. It belongs to agro-ecological zone (AEZ) number 28 known as Madhupur Tract. The average annual rainfall is 2000 mm with more than 80% of it occurring from mid-June to the end of September. Mean temperature is lowest (15°C) in January and highest (30°C) in May.

The soil of the experimental field is Chhiata clay loam, a member of the fine, hyperthermic Vertic Endoaquept [2]. The initial soil chemical properties at 0 - 15 cm soil depth were as follows: pH 6.1, organic matter 2.02%, total N content 0.07%, available phosphorus (P) 10.14 mg·kg<sup>-1</sup> (0.5 M NaHCO<sub>3</sub> extracted), exchangeable potassium (K) 0.17 meq/100g soil (Neutral 1.0 N NH<sub>4</sub>OAc extracted), available sulfur (S) 20 mg·kg<sup>-1</sup> [Ca(H<sub>2</sub>PO<sub>4</sub>)<sub>2</sub> extracted], and available zinc (Zn) 2.8 mg·kg<sup>-1</sup> (0.01 N HCl extracted).

In Bangladesh context two popular mega winter rice varieties BRRI dhan28 and BRRI dhan29 were grown in the experimental field under fully irrigated conditions during *boro*'2010-2011 (November-April) season. BRRI dhan28 is a short duration high yielding *boro* variety (growth duration 145 days) and BRRI dhan29 is a long duration high yielding *boro* variety (growth duration 160 days). These two varieties were transplanted in first week of January with 40 - 45 days old seedlings and harvested in May. Two/three rice seedlings were transplanted maintaining 20 × 20 cm spacing. The seed rate for rice was 30 kg·ha<sup>-1</sup>. The experiment was conducted in a randomized complete block design with four replications. Unit plot size was 5 × 4 m. All plots were surrounded by soil levees 30 cm high to avoid N contamination between plots. After transplanting the seedlings, intercultural operations like weeding, irrigation and control of pest were done as and when necessary for better growth and development of rice plants. At maturity the crop was harvested manually at 15 cm above ground level, however, 16 hills from each plot were harvested at the ground level for measuring yield components and straw yield. The grain yield was recorded at 14% moisture content and straw yield as oven dry basis following standard procedures as described by [14]. The 16 hills were selected at random in each plot just before harvesting to estimate plant height and tiller and panicle number. The grain number panicle<sup>-1</sup>, weight of 1000 grains, harvest index and sterility (%) were calculated by following standard procedures as described by [15].

Harvest index (HI) was computed by dividing the grain yield by the total dry matter (grain yield + straw yield) and was expressed as percentage as follows:

$$HI = \left( \frac{\text{Grain yield}}{\text{Grain yield} + \text{Straw yield}} \right) \times 100.$$

Sterility was computed by dividing the number of unfilled spikelets by the total number of spikelets (filled grains + unfilled spikelets) and was expressed as percentage as follows:

$$\text{Sterility}(\%) = \left( \frac{\text{Unfilled spikelets}}{\text{Unfilled spikelets} + \text{filled grains}} \right) \times 100.$$

Rice plants from 5 m<sup>2</sup> area of the middle of each plot were harvested and threshed. The grains were dried in sunlight and winnowed before weighing and yield was adjusted to 14% moisture content and was converted into t·ha<sup>-1</sup>. Six treatments were consisted as follows: 1) N control (0 kg N ha<sup>-1</sup>), 2) Optimum dose of nitrogen (164 kg·ha<sup>-1</sup>) from urea 3) 50% N from urea and 50% N from cowdung (CD), 4) 50% N from urea and 50% N from poultry manure (PM), 5) 100% N from CD and 6) 100% N from from PM.

Nitrogen was top dressed as urea in three equal splits: 20, 35 and 50 days after transplanting (DAT) for BRRI dhan28 and 20, 35 and 55 DAT for BRRI dhan29. Phosphorus, K, S and Zn were applied as triple super phosphate, muriate of potash, gypsum and zinc sulphate, respectively, during final land preparation. The CD and PM were applied on a dry weight basis and mixed well with the soil, by manual digging, about two weeks before transplanting of rice. The CD was collected from the BRRI cattle shed and PM was collected from a nearby poultry farm. Nutrient concentrations in CD and PM were determined. The N, P, K and S concentration in CD (oven dry basis) were 0.85%, 0.33%, 0.52% and, 0.08% and those in PM were 2.28%, 1.03%, 1.20% and 0.24%, respectively.

Nitrogen was determined from the collected plant samples. Grain and straw samples from each plot (200 mg) were taken and separately oven dried at 65°C over night to grind in a grinding machine. The ground sample was

digested in concentrated  $H_2PO_4$  and total N concentration was determined by micro Kjeldahl method [14]. Total N uptake was determined by the following formulae:

$$\text{Nitrogen uptake by grain (kg}\cdot\text{ha}^{-1}) = \frac{\% \text{ N in grain} \times \text{Grain yield (kg}\cdot\text{ha}^{-1})}{100}$$

$$\text{Nitrogen uptake by straw (kg}\cdot\text{ha}^{-1}) = \frac{\% \text{ N in straw} \times \text{straw yield (kg}\cdot\text{ha}^{-1})}{100}$$

Nitrogen use efficiencies were calculated using the following formulas [16]:

*Agronomic efficiency (AE)*. It is expressed as difference in grain yield between fertilized and unfertilized plot divided by the quantity of nutrient applied. It is expressed as  $\text{kg}\cdot\text{kg}^{-1}$ .

$$AE = \frac{(G_f - G_u)}{N_a}$$

where  $G_f$  is the grain yield of the fertilized plot (kg),  $G_u$  is the grain yield of the unfertilized plot (kg), and  $N_a$  is the quantity of N applied (kg).

*Physiological use efficiency (PE)*. The physiological efficiency is the difference in biological (grain + straw) yield between fertilized and unfertilized plots over difference in nutrient uptake between fertilized and unfertilized plots. It is expressed as  $\text{kg}\cdot\text{kg}^{-1}$ .

$$PE = \frac{(Y_f - Y_u)}{(N_{ff} - N_{uu})}$$

where  $Y_f$  is the total biological yield (grain plus straw) of the fertilized plot (kg),  $Y_u$  is the total biological yield of the unfertilized plot (kg),  $N_{ff}$  is the nutrient accumulation of the fertilized plot (kg), and  $N_{uu}$  is the nutrient accumulation of the unfertilized plot (kg).

*Agrophysiological efficiency (APE)*. The difference in grain yield between fertilized and unfertilized plots divided by the difference in nutrient uptake in them is known as agrophysiological efficiency (APE).

$$APE = \frac{(G_f - G_u)}{(N_{ff} - N_{uu})}$$

where  $G_f$  is the grain yield of the fertilized plot (kg),  $G_u$  is the grain yield of the unfertilized plot (kg),  $N_{ff}$  is the N accumulation by straw and grains in the fertilized plot (kg),  $N_{uu}$  is the N accumulation by straw and grains in the unfertilized plot (kg). The unit of agrophysiological efficiency is  $\text{kg}\cdot\text{kg}^{-1}$ .

*Apparent recovery efficiency (ARE)*. It states that the percentage of the applied nutrient that is apparently absorbed the crop.

$$ARE = \frac{(N_f - N_u) \times 100}{N_a}$$

where  $N_f$  is the N accumulation by the total biological yield (grain plus straw) in the fertilized plot (kg),  $N_u$  is the N accumulation by the total biological yield (grain plus straw) in the unfertilized plot (kg), and  $N_a$  is the quantity of N applied (kg).

*Utilization efficiency (UE)*. The product of physiological efficiency and apparent recovery efficiency is known as utilization efficiency (UE). Essentially, the UE is dimensionless.

$$UE = PE \times ARE$$

*Partial factor productivity (PFP)*. The grain yield per quantity of nutrient applied, is considered as partial factor productivity (PFP). It is also unitless.

$$PFP = \frac{G_f}{N_a}$$

*Internal use efficiency of applied nitrogen (IUE)*. It is calculated using the following formula:

$$\text{IUE} = \frac{\text{GY}}{\text{UN}} \times 100$$

where, GY is the grain yield ( $\text{kg}\cdot\text{ha}^{-1}$ ) and UN is the total N uptake ( $\text{kg}\cdot\text{ha}^{-1}$ ).

*Reciprocal of Internal use efficiency (RIUE)*: It is the reverse calculation of IUE.

Analysis of variance (ANOVA) of the measured parameters was performed and the treatment means were compared using Least Significant Difference (LSD) at the 5% level of probability [17]. The yield and N uptake parameters were analyzed by ordinary least squares linear regression as done by [18]. The significance test of the regression analysis was done following [19].

### 3. Results and Discussion

#### 3.1. Tiller Production at Maturity

Nitrogen sources (N) and variety (V) interactions showed significant effect ( $P < 0.01$ ) on tiller production at maturity. The individual effects of N and V for tiller production was also significant ( $P < 0.01$ ) (Table 1). The N control plots produced tiller number of 224 and 218 per  $\text{m}^2$  in BRRRI dhan28 and BRRRI dhan29. In BRRRI dhan28 the absolute urea treatment increased the number of tiller to 321 per  $\text{m}^2$  followed by urea + CD treatment (313  $\text{m}^{-2}$ ). The urea + CD treatment and urea + PM treatment gave statistically similar number of tillers. The absolute CD treatment and the absolute PM treatment produced statistically similar number of tillers. The absolute urea treatment gave significantly higher tiller in comparison to that of absolute CD treatment and absolute PM treatment. In BRRRI dhan29, the absolute urea treatment gave the highest number of tillers (383  $\text{m}^{-2}$ ) followed by urea + PM treatment (373  $\text{m}^{-2}$ ). The absolute PM treatment and urea + CD treatment gave statistically similar number of tillers. The absolute CD treatment gave significantly lower tiller production compared to that of urea + CD treatment. Irrespective of N sources, BRRRI dhan29 produced significantly higher number of tillers compared to BRRRI dhan28 except N control and absolute CD treatment. On the other hand, the absolute CD treatment produced of 261 and 256 tillers per  $\text{m}^2$  in BRRRI dhan28 and BRRRI dhan29, respectively.

#### 3.2. Panicle Production

Nitrogen sources (N) and variety (V) interactions for panicle production were significant ( $P < 0.01$ ). The individual effect of N for panicle production was also significant ( $P < 0.01$ ) (Table 1). In BRRRI dhan28, the urea treatment gave the highest number of panicle followed by urea + CD treatment and urea + PM treatment. The absolute CD and absolute PM gave statistically similar number of panicles. The N control treatment gave the lowest number of panicles. All the N treatments produced significantly higher number of panicles in comparison to N control treatments. In BRRRI dhan29, the urea treatment gave the highest number of panicles followed by urea + PM treatment. The urea + CD treatment, urea + PM treatment and absolute PM treatment gave statistically similar number of panicles. All the treatments produced significantly higher number of panicles in comparison to N control treatment as well as BRRRI dhan28 (Table 1). Under urea treatment, BRRRI dhan29 gave significantly higher number of panicles compared to BRRRI dhan28. Under urea + CD treatment, urea + PM treatment and absolute PM treatment, BRRRI dhan29 gave significantly higher number of panicles compared to BRRRI dhan28. An exception was observed in N control treatment and absolute CD treatment. Under N control treatment, BRRRI dhan28 and BRRRI dhan29 produced statistically similar number of panicle production. Similarly, under absolute CD treatment, BRRRI dhan28 and BRRRI dhan29 gave statistically similar panicle production (Table 1).

#### 3.3. Grain Yield

Interaction of nitrogen sources (N) and variety (V) for grain yield demonstrated insignificant ( $P > 0.05$ ) effect, however, both the variety and sources of N, individually, produced significant effect on the rice grain yield ( $P < 0.01$ ). BRRRI dhan29 out yielded BRRRI dhan28 at all N treatments including the control and application of N through organic or inorganic sources increased grain yield dramatically in both the varieties (Table 1). In the control plots, BRRRI dhan28 gave  $3.80 \text{ t}\cdot\text{ha}^{-1}$  compared to  $4.53 \text{ t}\cdot\text{ha}^{-1}$  in BRRRI dhan29. The application of N through urea increased grain yield over the N control by about  $2.89 \text{ t}\cdot\text{ha}^{-1}$  in BRRRI dhan28 and  $3.01 \text{ t}\cdot\text{ha}^{-1}$  in BRRRI dhan29. Sharing the N between urea and CD decreased yield significantly in both the varieties compared

**Table 1.** Tiller and panicle production and yields of two rice varieties as influenced by different nitrogen sources.

Nitrogen sources (N) (kg·ha <sup>-1</sup> )	Tiller m <sup>-2</sup> (No.)	Panicle m <sup>-2</sup> (No.)	Grain yield (t·ha <sup>-1</sup> )	Straw yield (t·ha <sup>-1</sup> )
BRRi dhan28				
Control	224	214	3.80	4.22
Urea	321	309	6.69	6.94
Urea + CD	313	299	6.07	6.33
CD	261	250	4.61	4.85
Urea + PM	301	286	6.46	6.52
PM	274	265	6.46	6.61
Avg.	282	271	5.68	5.91
BRRi dhan29				
Control	218	209	4.53	5.02
Urea	383	361	7.54	7.73
Urea + CD	361	346	7.35	7.66
CD	256	243	5.63	5.76
Urea + PM	373	347	7.63	7.94
PM	362	346	7.10	7.32
Avg.	326	309	6.63	6.91
LSD <sub>0.05</sub> for N	29.27	28.48	0.25	0.33
LSD <sub>0.05</sub> for V	16.90	16.44	0.15	0.19
LSD <sub>0.05</sub> for N × V	41.40	40.28	NS	NS
CV (%)	9.5	9.7	4.0	5.0

NS: non-significant at the 0.05 probability levels.

to that obtained with urea. But the urea + CD treatment gave a yield advantage of 2.27 and 2.82 t·ha<sup>-1</sup>, compared to control, in BRRi dhan28 and BRRi dhan29, respectively. When the entire N was applied solely through CD, the grain yield decreased to 4.61 and 5.63 t·ha<sup>-1</sup> in BRRi dhan28 and BRRi dhan29, respectively. These yields were statistically lowest among the N treatments in both the varieties, however, significantly higher than that obtained with the inherent soil N. The urea + PM treatment gave similar yield to that of urea in both the varieties, however, BRRi dhan29 gave about 1.17 t·ha<sup>-1</sup> higher yield than BRRi dhan28. The PM treatment gave similar yield to that with urea + PM in BRRi dhan28, but BRRi dhan29 gave significantly lower in PM than the urea + PM. About 0.73 t·ha<sup>-1</sup> yield advantage with BRRi dhan29 compared to BRRi dhan28 explained the fact that the former variety has capacity of exploiting soil inherent N of about 10 kg more than the latter variety. Apparent N recovery (ANR) was higher for chemical N application compared to organic N treatments. [20] and [21] reported nitrogen availability as 30% for cow manure and 70% for PM while [22] reported it as 10% - 25% for CM and 30% - 50% for PM in the fertile soil of a pot experiment. However, relatively lower ANR for manure application was observed in this study. For CM application, not only ANR but also plant dry matter weight and plant N accumulation were lower compared to the other treatments. Therefore, only CM application might not produce an optimal rice yield. Recently, many researchers including [23] [24] and [25] indicated that use of organic manures in conjunction with mineral fertilizer is very important for ensuring better soil health and sustaining crop productivity. Therefore, a mix application of manures with mineral N fertilizer might provide high inorganic N in soil and higher crop production.

### 3.4. Straw Yield

The individual effect of nitrogen source (N) for straw yield was highly significant ( $P < 0.01$ ) (**Table 1**). In BRR1 dhan28, the absolute urea treatment gave the higher straw yield ( $6.94 \text{ t}\cdot\text{ha}^{-1}$ ) followed by absolute PM treatment ( $6.61 \text{ t}\cdot\text{ha}^{-1}$ ) and urea + PM treatment ( $6.52 \text{ t}\cdot\text{ha}^{-1}$ ). The absolute PM treatment and absolute CD treatment gave the straw yield of  $6.61 \text{ t}\cdot\text{ha}^{-1}$  and  $4.85 \text{ t}\cdot\text{ha}^{-1}$ , respectively. The absolute PM treatment gave significantly higher straw yield than that of absolute CD treatment. On the other hand, absolute urea treatment gave significantly higher straw yield ( $6.94 \text{ t}\cdot\text{ha}^{-1}$ ) than that of urea + CD treatment ( $6.33 \text{ t}\cdot\text{ha}^{-1}$ ). The urea + CD treatment and urea + PM treatment gave statistically similar straw yield ( $6.33 \text{ t}\cdot\text{ha}^{-1}$  and  $6.52 \text{ t}\cdot\text{ha}^{-1}$ , respectively). In BRR1 dhan29, the urea + PM treatment gave higher straw yield ( $7.94 \text{ t}\cdot\text{ha}^{-1}$ ) followed by urea treatment ( $7.73 \text{ t}\cdot\text{ha}^{-1}$ ) and urea + CD treatment ( $7.66 \text{ t}\cdot\text{ha}^{-1}$ ). The absolute PM treatment gave significantly lower straw yield ( $7.32 \text{ t}\cdot\text{ha}^{-1}$ ) in comparison to urea + PM treatment ( $7.94 \text{ t}\cdot\text{ha}^{-1}$ ). The absolute CD treatment gave significantly lower straw yield ( $5.76 \text{ t}\cdot\text{ha}^{-1}$ ) compared to absolute PM treatment ( $7.32 \text{ t}\cdot\text{ha}^{-1}$ ). On the other hand, urea + CD treatment gave significantly higher straw yield ( $7.66 \text{ t}\cdot\text{ha}^{-1}$ ) in comparison to absolute CD treatment ( $5.76 \text{ t}\cdot\text{ha}^{-1}$ ). The urea + CD treatment and urea + PM treatment gave statistically similar straw yield. The lowest straw yield was obtained from N control treatment in both the varieties (**Table 1**). The individual effect of variety V for straw yield was significant ( $P < 0.01$ ). In N control treatment, BRR1 dhan29 gave significantly higher straw yield ( $5.02 \text{ t}\cdot\text{ha}^{-1}$ ) in comparison to BRR1 dhan28 ( $4.22 \text{ t}\cdot\text{ha}^{-1}$ ). In urea treatment, BRR1 dhan28 and BRR1 dhan29 gave the straw yield of  $6.94 \text{ t}\cdot\text{ha}^{-1}$  and  $7.73 \text{ t}\cdot\text{ha}^{-1}$ , respectively. Under this treatment BRR1 dhan29 gave the highest straw yield in comparison to BRR1 dhan28. Under urea + CD treatment and absolute CD treatment, BRR1 dhan29 gave significantly higher straw yields in comparison to BRR1 dhan28. Under urea + PM treatment, BRR1 dhan29 also gave significantly higher straw yield compared to BRR1 dhan28. A similar trend of straw yield was also observed in absolute PM treatment.

### 3.5. Grains Panicle<sup>-1</sup>

Nitrogen sources (N) and variety (V) interactions were significant ( $P < 0.05$ ) for the number of grains per panicle. The individual effect of N for grains panicle<sup>-1</sup> was highly significant ( $P < 0.01$ ) (**Table 2**). The N control plots produced the lowest grains per panicle in both the varieties—78 in BRR1 dhan28 and 92 in BRR1 dhan29. In case of BRR1 dhan28, urea + CD gave the similar number of grains per panicle as obtained in the N control plot, but in this treatment BRR1 dhan29 increased grains per panicle significantly higher than the N control. BRR1 dhan28 increased grains per panicle in urea, CD, PM and urea + PM treatment than the N control plots, but the difference among urea, CD, PM and urea + PM was not significant. The application of N increased grains per panicle significantly higher than that obtained in the N control in BRR1 dhan29. Among the N sources, the lowest grain per panicle was found in CD treatment. Both the urea and urea + CD treatment produced significantly higher number of grains panicle<sup>-1</sup> compared to the CD. Similarly urea + PM and PM treatment increased grains per panicle in comparison to that in urea and urea + CD treatment. The difference in grains per panicle between BRR1 dhan28 and BRR1 dhan29 was larger in urea + CD, urea + PM and PM compared to that in urea treatment. Both the N control and CD treatment showed similar difference in grains per panicle between the two tested varieties, but the difference was larger in urea than in N control and CD treatment. In the N control and CD treatments, BRR1 dhan29 gave 14 and 13 more grain than the BRR1 dhan28. In the urea treatment, the difference was 23, while in other treatments BRR1 dhan29 gave 34 - 37 more grains per panicle than in BRR1 dhan28.

### 3.6. 1000-Grain Weight

Nitrogen sources (N) × variety (V) interactions were insignificant for 1000-grain weight ( $P > 0.05$ ). The individual effect of N was also insignificant ( $P > 0.05$ ) for 1000-grain weight (**Table 2**). In BRR1 dhan28, 1000-grain weight was produced of 22 g in all N treatments. In BRR1 dhan29, 1000-grain weight ranged from 22 - 24 g among the N treatments. The individual effect of (V) was significant ( $P < 0.01$ ) for 1000-grain weight. BRR1 dhan29 gave higher 1000-grain weight in comparison to BRR1 dhan28 except absolute PM treatment. The absolute PM treatment gave 22 g 1000-grain weight in BRR1 dhan29.

### 3.7. Sterility Percentage

In BRR1 dhan28, the higher sterility (%) was obtained from urea treatment followed by urea + CD treatment and

**Table 2.** Different yield parameters of two rice varieties as influenced by different nitrogen sources.

Nitrogen source (N) (kg·ha <sup>-1</sup> )	Grains panicle <sup>-1</sup>	1000 grain wt (g)	Sterility (%)	Harvest index
<b>BRRi dhan28</b>				
Control	78	22	6.20	0.44
Urea	90	22	17.52	0.45
Urea + CD	79	22	16.34	0.45
CD	87	22	10.02	0.45
Urea + PM	86	22	15.58	0.46
PM	88	22	14.12	0.46
Avg.	85	22	13.30	0.45
<b>BRRi dhan29</b>				
Control	92	23	21.81	0.44
Urea	113	24	18.79	0.46
Urea + CD	113	24	21.63	0.45
CD	100	24	25.09	0.46
Urea + PM	123	24	18.77	0.45
PM	123	22	17.54	0.46
Avg.	111	24	20.61	0.45
LSD <sub>0.05</sub> for N	9.55	NS	NS	0.005
LSD <sub>0.05</sub> for V	5.51	0.74	2.02	NS
LSD <sub>0.05</sub> for N × V	13.50	NS	4.94	NS
CV (%)	9.6	5.6	20.3	1.2

NS: non-significant at the 0.05 probability levels.

urea + PM treatment. The urea + PM treatment and absolute PM treatment gave statistically similar sterility (%). The absolute PM treatment gave significantly higher sterility (%) compared to absolute CD treatment. All the N treatments gave significantly higher sterility (%) in comparison to N control treatment. A different scenario was observed in BRRi dhan29. In BRRi dhan29, the absolute CD treatment gave the highest sterility followed by N control treatment and urea + CD treatment. The urea treatment, urea + PM treatment and absolute PM treatment produced statistically similar sterility. The absolute CD treatment gave significantly higher sterility compared to absolute PM treatment. Regardless of N sources BRRi dhan29 produced higher sterility than the BRRi dhan28. Under urea + CD treatment, BRRi dhan29 gave significantly higher sterility compared to BRRi dhan28. A similar scenario was also observed in absolute CD treatment. But under urea treatment, BRRi dhan28 and BRRi dhan29 gave statistically similar sterility. Under urea + PM treatment BRRi dhan29 produced higher sterility compared to BRRi dhan28. A similar scenario was also observed in absolute PM treatment (**Table 2**).

### 3.8. Harvest Index

In both the tested varieties (BRRi dhan28 and BRRi dhan29) the harvest index (HI) varied from 0.44 to 0.46. The N control plots gave the lowest harvest index in both the varieties. The application of N increased HI slightly. In BRRi dhan28, the urea + PM treatment and absolute PM treatment gave the higher HI followed by absolute urea treatment, urea + CD treatment and absolute CD treatment. In BRRi dhan29, the absolute urea treatment, absolute CD treatment and absolute PM treatment gave the higher HI (0.46) followed by urea + CD



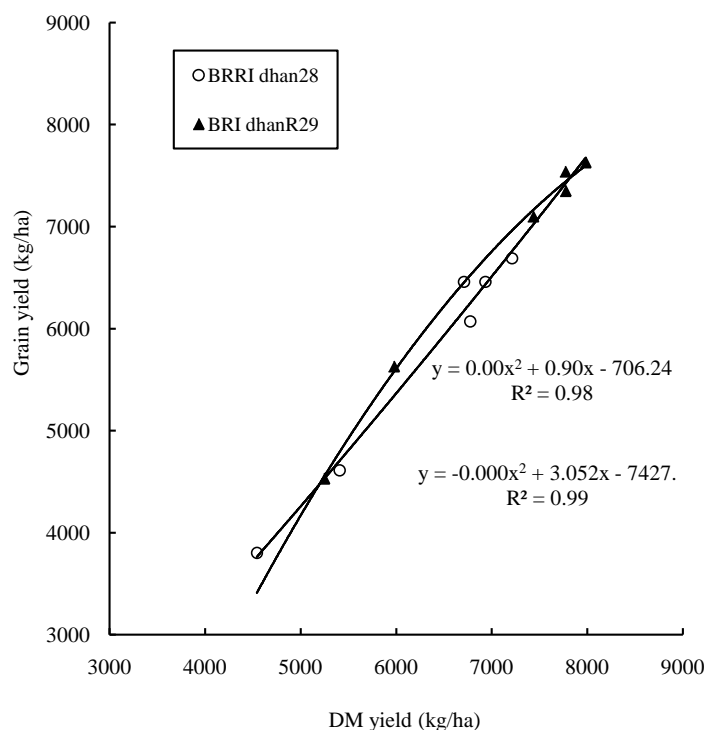
treatment and urea + PM treatment (0.45) (Table 2).

### 3.9. Relationship between Dry Matter at Harvest and Grain Yield

A relationship between dry matter at harvest and grain yield was determined in BRRi dhan28 and BRRi dhan29. Grain yield increased significantly ( $P < 0.01$ ) and quadratically with increasing dry matter in both the varieties. The quadratic regression equation ( $Y = -0.0x^2 + 3.1x - 7427.9$  for BRRi dhan28 and  $Y = 0.00x^2 + 0.90x - 706.24$  for BRRi dhan29) can explain 99% of the relationship for BRRi dhan28 ( $R^2 = 0.99$ ) and 98% of the relationship for BRRi dhan29 ( $R^2 = 0.98$ ). Maximal grain yields of about  $6690 \text{ kg}\cdot\text{ha}^{-1}$  were achieved at about  $7214 \text{ kg}\cdot\text{ha}^{-1}$  of dry matter production in BRRi dhan28, with a harvest index of about 0.46 and  $7630 \text{ kg}\cdot\text{ha}^{-1}$  were achieved at about  $7983 \text{ kg}\cdot\text{ha}^{-1}$  of dry matter production in BRRi dhan29, with a harvest index of about 0.46 (Figure 1). [26] reported that grain yield in cereals is related to biological yield and harvest index. The biological yield of a cereal crop is the total yield of plant tops and is an indication of the yield of the photosynthetic capability of the crop in question.

### 3.10. Nitrogen Uptake at Harvesting Stage

Nitrogen (N)  $\times$  variety (V) interactions and the individual effect of V for straw nitrogen uptake (SNUP), grain nitrogen uptake (GNUP) and total nitrogen uptake (TNUP) were insignificant ( $P > 0.05$ ). The individual effect of N was significant ( $P < 0.01$ ) for SNUP, GNUP and TNUP (Table 3). In BRRi dhan28, the urea treatment and urea + PM treatment gave the higher N uptake in rice straw ( $38 \text{ kg}\cdot\text{ha}^{-1}$ ) followed by urea + CD treatment ( $36 \text{ kg}\cdot\text{ha}^{-1}$ ), absolute CD treatment ( $35 \text{ kg}\cdot\text{ha}^{-1}$ ) and absolute PM treatment ( $34 \text{ kg}\cdot\text{ha}^{-1}$ ). The urea + PM treatment had the highest N uptake in rice grain ( $66 \text{ kg}\cdot\text{ha}^{-1}$ ) followed by urea + CD treatment ( $62 \text{ kg}\cdot\text{ha}^{-1}$ ), urea treatment ( $60 \text{ kg}\cdot\text{ha}^{-1}$ ) and absolute PM treatment ( $55 \text{ kg}\cdot\text{ha}^{-1}$ ). The N control treatment had the lowest N uptake both in rice straw and rice grain (Figure 2). The urea + PM treatment had the highest TNUP ( $104 \text{ kg}\cdot\text{ha}^{-1}$ ) followed by urea treatment ( $98 \text{ kg}\cdot\text{ha}^{-1}$ ) and urea + CD treatment ( $98 \text{ kg}\cdot\text{ha}^{-1}$ ). The urea treatment, urea + CD treatment and absolute PM treatment gave statistically similar TNUP. The N control treatment had the lowest TNUP (Figure 2). In N control treatment, TNUP was  $45 \text{ kg}\cdot\text{ha}^{-1}$  of which 64% accumulated in rice grain and the rest 36% in

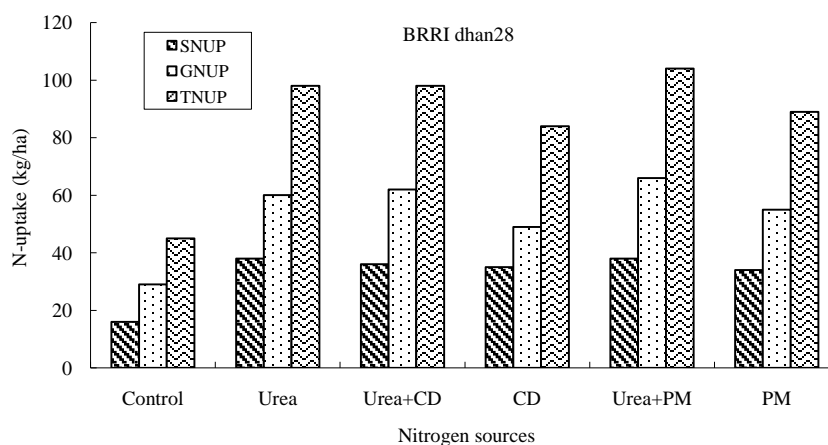


**Figure 1.** Relationship between dry matter and grain yield production under different nutrient sources.

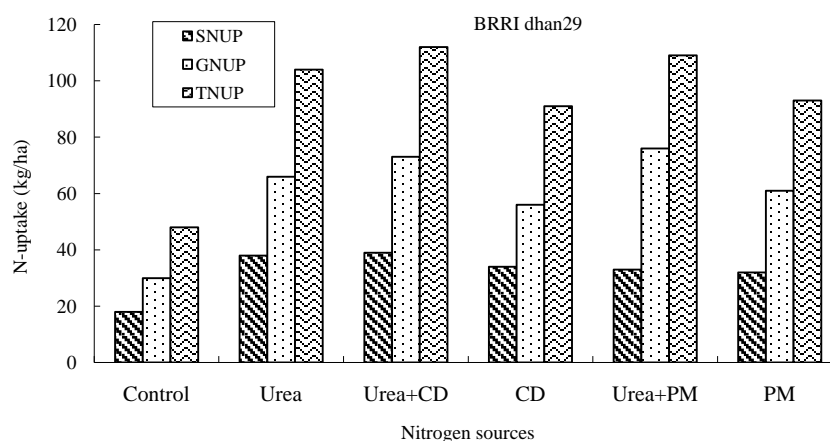
**Table 3.** Nitrogen uptake with different nitrogen treatments in BRRi dhan28 and BRRi dhan29.

Nitrogen source (N) (kg·ha <sup>-1</sup> )	SNUP (kg·ha <sup>-1</sup> )	GNUP (kg·ha <sup>-1</sup> )	TNUP (kg·ha <sup>-1</sup> )
<b>BRRi dhan28</b>			
Control	16	29	45
Urea	38	60	98
Urea + CD	36	62	98
CD	35	49	84
Urea + PM	38	66	104
PM	34	55	89
Average	33	54	87
NHI		0.63	
<b>BRRi dhan29</b>			
Control	18	30	48
Urea	38	66	104
Urea + CD	39	73	112
CD	34	56	91
Urea + PM	33	76	109
PM	32	61	93
Average	32	60	92
NHI		0.65	
LSD <sub>0.05</sub> for N	7.61	11.99	18.30
LSD <sub>0.05</sub> for V	NS	NS	NS
LSD <sub>0.05</sub> for N × V	NS	NS	NS
CV (%)	23.0	20.7	20.1

NS: non-significant at the 0.05 probability levels.

**Figure 2.** Relationship between nitrogen uptake and different nitrogen sources in BRRi dhan28.

rice straw. Under urea treatment, TNUP was  $98 \text{ kg}\cdot\text{ha}^{-1}$  of which 61% accumulated in rice grain and the rest 39% remained in rice straw. Under urea + CD treatment, TNUP was  $98 \text{ kg}\cdot\text{ha}^{-1}$  of which 63% N uptake was observed in rice grain and 37% N uptake was in rice straw. Under absolute CD treatment, TNUP was  $84 \text{ kg}\cdot\text{ha}^{-1}$  of which 58% N uptake was observed in rice grain and the rest 42% N uptake was in rice straw. Similarly, in urea + PM treatment and absolute PM treatment, TNUP was  $104 \text{ kg}\cdot\text{ha}^{-1}$  and  $89 \text{ kg}\cdot\text{ha}^{-1}$  of which 63% and 62% N uptake was observed in rice grain and the rest 37% and 38% was in rice straw, respectively (Table 3). In BRRI dhan29, the urea + CD treatment had the highest N uptake in rice straw ( $39 \text{ kg}\cdot\text{ha}^{-1}$ ) followed by absolute urea treatment ( $38 \text{ kg}\cdot\text{ha}^{-1}$ ) and absolute CD treatment ( $34 \text{ kg}\cdot\text{ha}^{-1}$ ). The absolute CD treatment, urea + PM treatment and absolute PM treatment gave statistically similar N uptake in rice straw. The N control treatment had the lowest N uptake in rice straw ( $18 \text{ kg}\cdot\text{ha}^{-1}$ ) (Figure 3). The urea + PM treatment had the highest N uptake in rice grain ( $76 \text{ kg}\cdot\text{ha}^{-1}$ ) followed by urea + CD treatment ( $73 \text{ kg}\cdot\text{ha}^{-1}$ ) and urea treatment ( $66 \text{ kg}\cdot\text{ha}^{-1}$ ). The urea treatment, absolute PM treatment and absolute CD treatment gave statistically similar N uptake in rice grain. The N control treatment had the lowest N uptake in rice grain ( $30 \text{ kg}\cdot\text{ha}^{-1}$ ) (Figure 3). The urea + CD treatment had the highest TNUP ( $112 \text{ kg}\cdot\text{ha}^{-1}$ ) followed by urea + PM treatment ( $109 \text{ kg}\cdot\text{ha}^{-1}$ ) and urea treatment ( $98 \text{ kg}\cdot\text{ha}^{-1}$ ). The absolute CD treatment and absolute PM treatment gave statistically similar TNUP. The N control treatment gave the lowest TNUP ( $48 \text{ kg}\cdot\text{ha}^{-1}$ ) (Figure 3). In BRRI dhan29, TNUP was  $48 \text{ kg}\cdot\text{ha}^{-1}$  of which 62% N uptake was observed in rice grain and the rest 38% N uptake was in rice straw under N control treatment. In urea treatment, TNUP was  $104 \text{ kg}\cdot\text{ha}^{-1}$  of which 63% N uptake was observed in rice grain and the rest 37% N uptake was in rice straw. In urea + CD treatment, TNUP was  $112 \text{ kg}\cdot\text{ha}^{-1}$  of which 65% N uptake was observed in rice grain and the rest 35% N uptake was in rice straw. In absolute CD treatment, TNUP was  $91 \text{ kg}\cdot\text{ha}^{-1}$  of which 62% N uptake was occurred in rice grain and the rest 38% N uptake was observed in rice straw. In urea + PM treatment, TNUP was  $109 \text{ kg}\cdot\text{ha}^{-1}$  of which 70% N uptake was observed in rice grain and the rest 30% was remained in rice straw. In absolute PM treatment, TNUP was  $93 \text{ kg}\cdot\text{ha}^{-1}$  of which 66% N uptake was observed in rice grain and the rest 34% N uptake was in rice straw. Irrespective of N treatments, average TNUP in BRRI dhan28 was  $87 \text{ kg}\cdot\text{ha}^{-1}$  of which 62% N uptake in rice grain and the rest 38% N uptake was in rice straw. Similarly in BRRI dhan29, average TNUP was  $92 \text{ kg}\cdot\text{ha}^{-1}$  of which 65% N uptake was observed in rice grain and the rest 35% N uptake was in rice straw (Table 3). In both the varieties, GNUP was higher in comparison to SNUP in all the treatments. Because N uptake increased dry matter production up to flowering stage and decreased thereafter due to pollen falls and tiller senescence. [26] reported that at harvest, more N was accumulated in grains than in dry matter. It might be explained by the N harvest index (N accumulation in grains/N accumulation in grains plus dry matter). In BRRI dhan28, nitrogen harvest index (NHI) across the nitrogen treatments was 0.63. This means that 63% of the absorbed N was translocated to the grains and 37% remained in the dry matter. In BRRI dhan29, the NHI value was 0.65. This also means that 65% of the absorbed N was translocated to the grain and 35% remained in the dry matter. [27] reported that NHI values varied from 0.60 to 0.72 for three IRRI semi dwarf rice cultivars differing in growth duration. [28] reported NHI values of 0.58 and 0.62 in two lowland rice cultivars in West Africa.



**Figure 3.** Relationship between nitrogen uptake and different nitrogen sources in BRRI dhan29.

### 3.11. Nitrogen Use Efficiency (NUE)

Application of  $164 \text{ kg N ha}^{-1}$  through different sources influenced nitrogen use efficiency. In BRRRI dhan28, the urea treatment had the highest AE ( $18 \text{ kg}\cdot\text{kg}^{-1}$ ) followed by urea + PM treatment ( $16 \text{ kg}\cdot\text{kg}^{-1}$ ) and absolute PM treatment ( $16 \text{ kg}\cdot\text{kg}^{-1}$ ). The AE of urea + CD treatment was significantly lower in comparison to urea treatment, urea + PM treatment and absolute PM treatment. The absolute CD treatment had the lowest AE ( $5 \text{ kg}\cdot\text{kg}^{-1}$ ). It was probably due to slow mineralization of CD in comparison to urea and PM. In BRRRI dhan28, the average AE was  $14 \text{ kg grain produced per kg N applied}$  across N sources. In BRRRI dhan29, the urea + PM treatment had the highest AE ( $19 \text{ kg}\cdot\text{kg}^{-1}$ ) followed by absolute urea treatment ( $18 \text{ kg}\cdot\text{kg}^{-1}$ ). The urea + CD treatment gave significantly higher AE in comparison to absolute CD treatment. The urea + CD treatment and absolute PM treatment gave similar AE. The absolute CD treatment had the lowest AE ( $7 \text{ kg}\cdot\text{kg}^{-1}$ ). In BRRRI dhan29, the average AE was  $15 \text{ kg grain produced per kg N applied}$  across N sources. Under urea + CD treatment, BRRRI dhan29 gave significantly higher AE in comparison to BRRRI dhan28. Under absolute urea treatment and absolute PM treatment BRRRI dhan28 and BRRRI dhan29 gave statistically similar AE.

Under absolute CD treatment and urea + PM treatment, BRRRI dhan29 gave significantly higher AE in comparison to BRRRI dhan28. The average agronomic efficiency (AE) was  $14 \text{ kg}\cdot\text{kg}^{-1}$  (*i.e.*  $14 \text{ kg grain produced per kg N applied}$ ) in BRRRI dhan28 and  $15 \text{ kg}\cdot\text{kg}^{-1}$  in BRRRI dhan29 across N sources. The use of urea solely or in conjunction with poultry manure gave comparatively higher AE than those of CD. Agronomic efficiency is usually greater at the quick mineralized material than slow mineralized material of N source. Poultry manure has a higher nutrient content and more rapid mineralization rate compared to other animal manures [29]. [26] reported that agronomic efficiency was  $23 \text{ kg grain produced per kg N applied}$  in flooded rice cultivar Metica 1. [5] also reported agronomic efficiency in lowland rice in the tropics in the range of  $15$  to  $25 \text{ kg grain produced per kg of applied N}$ . In BRRRI dhan28, the absolute PM treatment gave the highest physiological efficiency (PE) ( $144 \text{ kg}\cdot\text{kg}^{-1}$ ) followed by absolute urea treatment ( $117 \text{ kg}\cdot\text{kg}^{-1}$ ) (Table 4). In absolute PM treatment, PE was  $144 \text{ kg biological yield (straw + grain) per unit of N accumulated}$  whereas in urea treatment PE was  $117 \text{ kg biological yield per unit of N accumulated}$ . All the N sources gave statistically similar PE except absolute CD treatment. The absolute CD treatment had the lowest PE ( $38 \text{ kg}\cdot\text{kg}^{-1}$ ). In BRRRI dhan28, the average PE was  $94 \text{ kg biological yield per unit of N accumulated}$  across N sources. In BRRRI dhan29, the absolute PM treatment had the highest PE ( $167 \text{ kg}\cdot\text{kg}^{-1}$ ) followed by urea treatment ( $131 \text{ kg}\cdot\text{kg}^{-1}$ ) and urea + PM treatment ( $119 \text{ kg}\cdot\text{kg}^{-1}$ ). The absolute PM treatment gave significantly higher PE in comparison to urea + CD treatment. The absolute CD treatment had the lowest PE ( $48 \text{ kg}\cdot\text{kg}^{-1}$ ). In BRRRI dhan29, the average PE was  $110 \text{ kg biological yield per unit of N accumulated}$  across N sources. In BRRRI dhan28, the absolute PM treatment had the highest agro physiological efficiency (APE) ( $75 \text{ kg}\cdot\text{kg}^{-1}$ ) followed by absolute urea treatment ( $61 \text{ kg}\cdot\text{kg}^{-1}$ ). In absolute PM treatment, APE was  $75 \text{ kg grain produced per kg of N accumulated in the grain and straw}$  whereas in urea treatment  $61 \text{ kg grain produced per kg of N accumulated in the grain and straw}$ . All the N treatments gave statistically similar APE except absolute CD treatment. The absolute CD treatment had the lowest APE ( $21 \text{ kg}\cdot\text{kg}^{-1}$ ). In BRRRI dhan29, the absolute PM treatment had the highest APE followed by urea treatment ( $69 \text{ kg}\cdot\text{kg}^{-1}$ ) and urea + PM treatment ( $61 \text{ kg}\cdot\text{kg}^{-1}$ ). The APE from absolute PM treatment was significantly higher in comparison to that of urea + CD treatment. The absolute CD treatment had the lowest APE was observed in ( $28 \text{ kg}\cdot\text{kg}^{-1}$ ) (Table 4). [26] reported that APE was  $63 \text{ kg grain produced per kg of N accumulated in the grain and straw}$  across N rates. The apparent recovery efficiency (ARE) ranged from  $24\%$  -  $39\%$  irrespective of N sources and variety. [26] reported an apparent recovery efficiency of  $39\%$  across different N rates in flooded rice cultivar Metica 1. The percentage of N recovery varies with soil properties, methods, amounts and timing of fertilizer application and other management practices. It usually ranges from  $30\%$  -  $50\%$  in the tropics [30]. [31] also reported a N recovery efficiency of  $37\%$  in 20 lowland rice genotypes. The low N recovery efficiency in low land rice may be related to N losses from soil via nitrification-denitrification,  $\text{NH}_3$  volatilization, or leaching [32].

In BRRRI dhan28, the urea treatment had the highest utilization efficiency (UE) ( $34 \text{ kg}\cdot\text{kg}^{-1}$ ) followed by urea + PM treatment ( $30 \text{ kg}\cdot\text{kg}^{-1}$ ) and absolute PM treatment ( $31 \text{ kg}\cdot\text{kg}^{-1}$ ). The urea treatment gave significantly higher UE in comparison to urea + CD treatment. The absolute CD treatment had the lowest UE ( $9 \text{ kg}\cdot\text{kg}^{-1}$ ). In BRRRI dhan29, the urea + PM treatment had highest UE ( $37 \text{ kg}\cdot\text{kg}^{-1}$ ) followed by urea treatment ( $35 \text{ kg}\cdot\text{kg}^{-1}$ ) and urea + CD treatment ( $33 \text{ kg}\cdot\text{kg}^{-1}$ ). The urea + PM treatment gave significantly higher UE in comparison to absolute PM treatment. The absolute CD treatment had lowest UE ( $11 \text{ kg}\cdot\text{kg}^{-1}$ ). Under urea + CD treatment and urea + PM treatment, BRRRI dhan29 gave significantly higher UE in comparison to BRRRI dhan28. Under urea

**Table 4.** Nitrogen use efficiencies of two rice varieties under different nitrogen sources.

Nitrogen source (N) (kg·ha <sup>-1</sup> )	Agronomic efficiency (kg·kg <sup>-1</sup> )	Physiological efficiency (kg·kg <sup>-1</sup> )	Agro-physiological efficiency (kg·kg <sup>-1</sup> )	Apparent recovery efficiency (%)	Utilization efficiency (kg·kg <sup>-1</sup> )	Partial factor productivity (kg·kg <sup>-1</sup> )
BRRi dhan28						
Urea	18	117	61	33	34	41
Urea + CD	14	85	44	33	27	37
CD	5	38	21	24	9	28
Urea + PM	16	84	45	36	30	39
PM	16	144	75	27	31	39
Avg.	14	94	49	31	26	37
BRRi dhan29						
Urea	18	131	69	34	35	46
Urea + CD	17	87	45	39	33	45
CD	7	48	28	26	11	34
Urea + PM	19	119	61	37	37	47
PM	16	167	86	27	30	43
Avg.	15	110	58	33	29	43
LSD <sub>0.05</sub> for N	1.80	72.39	36.77	NS	4.30	1.66
LSD <sub>0.05</sub> for V	1.14	NS	NS	NS	2.72	1.05
LSD <sub>0.05</sub> for N × V	NS	NS	NS	NS	NS	NS
CV (%)	12.1	69.2	66.8	37.7	15.2	4.1

NS: non-significant at the 0.05 probability levels.

treatment, absolute CD treatment and absolute PM treatment, BRRi dhan28 and BRRi dhan29 gave statistically similar UE (Table 4.2.10). [26] reported that utilization efficiency was 58 kg·kg<sup>-1</sup> for flooded rice cultivar Metical *i.e.* 58 kg grain produced per kg N utilized across the N rates. [5] also reported that the efficiency of utilization for grain production in the tropics is about 50 kg grain per kg N absorbed, and this efficiency appears to be almost constant regardless of the rice yields achieved. In BRRi dhan28, the urea treatment gave the highest partial factor productivity (PFP) (41 kg·kg<sup>-1</sup>) followed by urea + PM treatment and absolute PM treatment (39 kg·kg<sup>-1</sup>). The absolute PM treatment and urea + PM treatment gave significantly higher PFP (39 kg·kg<sup>-1</sup>) in comparison to urea + CD treatment (37 kg·kg<sup>-1</sup>). The absolute CD treatment gave the lowest PFP (28 kg·kg<sup>-1</sup>). In BRRi dhan29, the urea + PM treatment gave the highest PFP (47 kg·kg<sup>-1</sup>) followed by urea treatment (46 kg·kg<sup>-1</sup>) and urea + CD treatment (45 kg·kg<sup>-1</sup>) (Table 4). The urea + CD treatment gave significantly higher PFP than the absolute PM treatment. The absolute CD treatment gave the lowest PFP (34 kg·kg<sup>-1</sup>). Application of same amount of N (164 kg·ha<sup>-1</sup>) from different sources varied the N-supplying capacity due to mineralization capacity of the materials. PFP was 40 kg grain produced per kg N applied averaged over N sources and varieties. The lowest PFP produced from absolute CD treatment due to slow mineralization of CD. In BRRi dhan28, the N control treatment gave the highest internal use efficiency (IUE) (86 kg·kg<sup>-1</sup>) followed by absolute PM treatment (75 kg·kg<sup>-1</sup>) and urea treatment (71 kg·kg<sup>-1</sup>). Urea + CD treatment and urea + PM treatment gave statistically similar IUE. The absolute CD treatment gave the lowest IUE (56 kg·kg<sup>-1</sup>). In BRRi dhan29, the N control treatment gave the highest IUE (94 kg·kg<sup>-1</sup>) followed by absolute PM treatment (81 kg·kg<sup>-1</sup>) and absolute urea treatment (77 kg·kg<sup>-1</sup>) (Table 5). Urea + PM treatment, urea + CD treatment and absolute CD treatment performed statistically similar IUE. The apparently lower IUE was observed in absolute CD treatment (64 kg·kg<sup>-1</sup>). Internal use efficiency was 72 kg·kg<sup>-1</sup> averaged over N sources and varieties *i.e.* were 72 kg grain produced per

**Table 5.** Nitrogen use efficiencies of two rice varieties under different nitrogen sources.

Nitrogen source (N) (kg·ha <sup>-1</sup> )	Internal use efficiency (IUE) (kg·kg <sup>-1</sup> )	Reciprocal of internal use efficiency (RIE) (kg·kg <sup>-1</sup> )
<b>BRRi dhan28</b>		
Control	86	12
Urea	71	15
Urea + CD	62	16
CD	56	18
Urea + PM	62	16
PM	75	14
Avg.	69	15
<b>BRRi dhan29</b>		
Control	94	11
Urea	77	14
Urea + CD	67	15
CD	64	16
Urea + PM	72	14
PM	81	13
Avg.	76	14
LSD <sub>0.05</sub> for N	15.02	2.91
LSD <sub>0.05</sub> for V	NS	NS
LSD <sub>0.05</sub> for N × V	NS	NS
CV (%)	20.4	19.7

NS: non-significant at the 0.05 probability levels.

kg of total N uptake in the grain and straw. [2] reported that the internal N use efficiency varied from 46 to 76 kg grain per kg plant N uptake across the treatments and years. In BRRi dhan28, reciprocal of internal use efficiency (RIUE) (kg N required to produced 1 ton of grain) varied from 12 - 18 kg·t<sup>-1</sup> and in BRRi dhan29, RIUE varied from 11 - 16 kg·t<sup>-1</sup>. The N control treatments gave the lowest RIUE in both the varieties (Table 5). In BRRi dhan28, the highest RIUE was observed in absolute CD treatment (18 kg·t<sup>-1</sup>) followed by urea + CD treatment (16 kg·t<sup>-1</sup>) and urea + PM treatment (16 kg·t<sup>-1</sup>). The absolute PM treatment, urea + PM treatment and urea treatment gave statistically similar RIUE. In BRRi dhan29, the absolute CD treatment gave the highest RIUE (16 kg·t<sup>-1</sup>) followed by urea + CD treatment (15 kg·t<sup>-1</sup>). The urea + PM treatment, urea treatment and absolute PM treatment gave statistically similar RIUE. [33] reported mean RIUE of 16.4 kg·t<sup>-1</sup> with full fertilization and 12.8 kg·t<sup>-1</sup> in -N plots.

#### 4. Conclusion

Managing the N application to rice is an essential to reduce N losses, improve N use efficiency and obtain higher yield. The use of urea solely or in conjunction with poultry manure gave comparatively higher N use efficiency than that of cowdung. Thus the doses of chemical fertilizer can be reduced by 50% by using poultry manure in dry season.

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