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Effects of Combined Application of Inorganic Fertilizer and Organic Manures on Nitrogen Use and Recovery Efficiencies of Hybrid Rice (Palethwe-1)

Kyi Moe[1,2*#], Kumudra Win Mg[2*], Kyaw Kyaw Win[2], Takeo Yamakawa[3]

[1]Plant Nutrition Laboratory, Graduate School of Bioresource and Bioenvironmental Sciences, Faculty of Agriculture, Kyushu University, Fukuoka, Japan
[2]Department of Agronomy, Yezin Agricultural University, Yezin, Myanmar
[3]Plant Nutrition Laboratory, Division of Molecular Biosciences, Department of Biosciences & Biotechnology, Faculty of Agriculture, Kyushu University, Fukuoka, Japan
Email: #kyimoeyau@gmail.com

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Abstract

We conducted two field experiments to investigate combined effects of organic and inorganic fertilizers on nitrogen use and recovery efficiencies of hybrid rice (Palethwe-1) during dry and wet seasons, 2015. Four levels of inorganic fertilizer (0%, 50%, 75%, and 100% NPK), based on recommended rates of 150 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1}, and 120 kg K_2O ha^{-1}, were used with cow manure, poultry manure, and vermicompost (5 t·ha^{-1}each) in a split-plot design with three replicates. In both seasons, with 50% NPK, the N uptake level achieved with poultry manure was similar to that obtained with 75% and 100% NPK. The greatest N use, internal, agronomic N use, and recovery efficiencies were obtained with 50% NPK + poultry manure, but were similar to those obtained from cow manure and vermicompost subplots. As the amount of applied N from organic and inorganic fertilizer increased, the N use efficiency and related parameters decreased, due to similar yields among plots with different NPK application levels. Poultry manure resulted in the highest significant correlations between applied N and N accumulation, followed by cow manure and vermicompost, in both seasons. Neither chemical fertilizer nor organic manure alone led to optimum N use and N recovery efficiencies. The combination of 50% inorganic fertilizer (75 kg N ha^{-1}) and poultry manure (5 t·ha^{-1}) enhanced the N uptake, the N use and recovery efficiencies of hybrid rice. Cow manure (5 t·ha^{-1}) in combination with 75% inorganic fertilizer (112.5 kg N ha^{-1}) was an adequate substitute for reduced chemical fertilizer usage. Therefore, this study highlighted combined application of inor-

*Equally contributed to this research.

ganic fertilizers and organic manures had the benefits not only in reducing the need for chemical fertilizers but also in improving N uptake by hybrid rice (Palethwe-1) leading to the better environment.

Keywords

Nitrogen Uptake, Nitrogen Use Efficiency, Nitrogen Recovery Efficiency, Agronomic Nitrogen Use Efficiency, Hybrid Rice

1. Introduction

Currently, global crop production requires inputs of roughly 105 million tons of nitrogen (N), 20 million tons of phosphorus (P), and 23 million tons of potassium (K) [1]. The recovery efficiency of applied fertilizer is low: ≤50% for N, <10% for P, and ~40% for K [2] [3]. However, in recent years, sustainable agriculture has received considerable attention from environmentalists, agriculturists, and consumers [4].

Rice constitutes one of the most important staple foods for over half of the world's population [5]. It is widely consumed by people throughout the world, irrespective of their race, religion, or political association [6]. In the central dry zone of Myanmar, rice is grown as a rain-fed crop, but is grown as an irrigated crop in areas where irrigation is available. The dry zones of the country are characterized by clay, sandy loam, and sandy soils that include gravel. According to Hadden [7], soil series in dry zones are of low fertility with low organic matter content. Moreover, K levels in agricultural plots located in dry zones are low.

N is required for all non-legume crops on all soil types. In rice cultivation, it is usually applied in the form of inorganic fertilizer, whereas the straw, which is used for animal feed, is seldom returned as the fertilizer to rice fields. This has contributed to a progressive decline in important soil components in agricultural land, a situation worsened by soil-intensive cropping and the use of high doses of chemical fertilizers with little or no addition of organic manure. Consequently, previous fertile soils have become degraded, with limited organic matter and nutrient contents.

In Myanmar, as in other areas of the world, inappropriate fertilization and the excessive use of N fertilizer have resulted in considerable N losses through ammonia (NH_3) volatilization and leaching [8] [9]. Consequently, nitrogen use efficiencies (NUEs) are as low as ~35% (15% ± 20% lower than other major rice growing countries) [9]. One of the main challenges in field management is to reduce the amount of N fertilizers applied in the field while avoiding N deficiency of the soils. Among the measures recommended for lowering N losses and enhancing NUE are the application of N at a later growth stage [8], adjusting the N rate based on chlorophyll readings [10], applying controlled-release N fertilizer [11], using urease inhibitors [12], planting highly efficient rice varieties [13], and combined organic and inorganic fertilizer applications [14].

Glaser *et al.* [15] concluded that losses of soil organic matter can only be replenished in the short term by the application of organic matter such as manures. However, organic manures may be of relatively low nutrient content and thus unlikely to meet the requirement of high-yielding rice varieties when used alone. The combined application of organic and inorganic fertilizers increases nutrient synchrony and reduces losses by converting inorganic N to organic forms [16], leading to sustainable productivity [17] [18]. Narwal and Chaudhary [19] reported that the combined application of organic manure and chemical fertilizer accelerates microbial activity, increases NUE, and enhances the availability of native nutrients to plants, resulting in higher nutrient uptake rates. A later study confirmed that, to provide plant nutrients in readily available forms and maintain good soil health, resulting in optimum yields, agricultural fields should be treated with both organic manures and inorganic fertilizers [20].

As demonstrated by Zadeh [21], farmyard manure not only acts as a source of N and other nutrients, but also increases the efficiency of applied N. Cow manure contains sufficient amounts of N and K as well as fibrous materials that favorably regulate soil moisture and temperature in addition to preventing weed growth on soil surfaces [22]. For rice production, cow manure, but also poultry manure, is a good source of organic matter and can play a vital role in improving soil fertility, by supplying nutrients, especially N, sulfur (S), K, and zinc (Zn) [23] [24]. Vermicompost has also been considered as a soil additive to reduce the use of mineral fertilizers, because it provides nutrients in the required amounts and increases both cation-exchange and water-retention capacities [25]. The application of fertilizers and manures of different composition will differentially influence the physical and chemical properties of the soil but ultimately enhance its biological activities [26].

In rice, NUE is the main parameter used to determine nutrient uptake [27]. In Asia, N fertilizer use is very high but in rice cultivation it is inefficient, as only 30% - 40% of the applied N is recovered [28]. The low NUE of rice reflects N loss in soil-plant systems, which has been explained not only by the dependence solely on chemical fertilizer application, but also by volatilization of NH_3, loss of nitrate (NO_3) from leaching, inadequate soil conditions, surface run off, soil erosion, environmental factors, and the use of nitrification inhibitors [29].

Thus, not surprisingly, annual rice production is facing a sustainability problem due to production practices that often result in the indiscriminate use of chemical fertilizers and pesticides [30] [31] [32] [33]. Alternative methods of rice production that are more economical and sustainable and can simultaneously improve NUE and minimize N losses are therefore needed. A possible approach to improving soil fertility and thereby crop productivity is the utilization of organic wastes, farm yard manure (FYM), compost, vermicompost, and poultry manures including their combined application with inorganic fertilizers. The use of organic matter to meet the nutrient requirement of crops would not only contribute to sustainable rice production but also ease the economic burden on poor farmers, who are unable to afford the increasingly costly chemical fertilizers. In fact, one of the few constraints on the use of fertilizer in crop production is its increasing cost [34]. In this study, we investigated the effects of organic fertilizer, alone or in combination with inorganic fertilizer, on N uptake (NU), NUE, and the N recovery efficiency (NRE) in the hybrid rice variety Palethwe-1.

2. Materials and Methods

2.1. Experimental Site

Two field experiments were conducted on the farm of the Department of Agronomy, Yezin Agricultural University, Nay Pyi Taw Division, Myanmar (19˚10'N, 96˚07'E) to study the combined effects of various organic manure and inorganic fertilizer levels on NUE and NRE of hybrid rice (Palethwe-1) (**Figure 1**). The first experiment (dry season) was conducted from January to April 2015 and the second (wet season) was conducted from August to November 2015.

Figure 1. Location of experimental site in Yezin Agricultural University, Nay Pyi Taw.

2.2. Experimental Design and Treatments

A split-plot design with three replications was used in the two field experiments. The size of each experimental plot was 3 × 5 m. The distances maintained between two replications and two plots were 2 and 0.5 m, respectively. Plots treated with inorganic fertilizers (NPK), applied in proportions of 0%, 50%, 75%, and 100% based on the recommended rates of 150 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1}, and 120 kg K_2O ha^{-1}, were designated as the main plots. Plots treated with organic manures (cow manure, poultry manure, and vermicompost; 5 t·ha^{-1} each) and the no organic manure control, were designated as subplots. The position of each treatment was not changed between the first and second field experiment.

The land was irrigated so as to be easily plowed, subsequently harrowed, and then divided into four parts (as the main plot area) for the application of the different inorganic fertilizers levels. Each main plot was divided into four subplots. Double bunds were created to prevent seepage between adjacent plots. The full amount of organic manure was applied during land preparation. Inorganic fertilizer consisting of urea (as the N source) and muriate of potash (K_2O source) was applied in three equal splits: one third before transplanting (baseline), one third at the active tillering stage, and one third at the panicle initiation stage. The full amount of triple superphosphate (P_2O_5 source) was applied as the basal dose.

2.3. Soil Sampling and Analysis

Baseline soil samples were collected from eight locations in the experimental field at a depth of 0 - 15 cm using a soil sampling tube (5 cm diameter). The samples were spread out, air dried at room temperature, crushed by hand, sifted through a 2-mm mesh sieve, and then analyzed for their physical and chemical properties.

The soil pH_{H2O} (1:5, soil:water) in mass ratio was measured using a pH meter F-51 HORIBA and the 4A1-1:5 soil water suspension method [35]. Available N (mg kg^{-1}) was extracted using the alkaline permanganate method [36], and available P (mg kg^{-1}) was analyzed using the 9C-Olsen P-Malachite green method [37] and a PD-303UV UV-VIS spectrophotometer. Available K (mg kg^{-1}) was measured after its extraction using 1 N ammonium acetate [38] followed by atomic absorption flame emission spectrophotometry (AA-6200, Shimadzu). The amount of organic matter (%) was determined using Tyurin's method [39], and the cation exchange capacity (CEC) using the leaching method [40]. Soil samples were analyzed at the Department of Agricultural Research (DAR) Yezin, Nay Pyi Taw, Myanmar.

2.4. Organic Manure Analysis

The cow manure, poultry manure, and vermicompost were placed in a temperature controlled oven and their nutrient contents then extracted for gravimetric analysis [41]. Total N was analyzed using the Kjeldahl method [42], followed by Kjeldahl digestion and distillation in a Vapodest 20 s distillation system (Gerhardt, Apparate GmbH & Co. KG, Germany). Total P was determined using the molybdovanadate-phosphoric acid method [43] and quantitated using a Jenway 6305 UV-VIS spectrophotometer. Total K was analyzed according to the wet digestion method [44] followed by atomic absorption spectrophotometry on an novAA 400 apparatus, and total S was determined using the turbidimetric method [45] and a Jenway 6305 UV-VIS spectrophotometer. Organic carbon was measured by the loss on ignition method [46] using a temperature-controlled oven (muffle furnace). The chemical composition of the organic manures (**Table 1**) was determined at the DAR.

2.5. Crop Management

The rice cultivated in this study was the hybrid rice (*Oryza sativa* L.) variety Palethwe-1. It is widely used in Myanmar because of its high potential yield. Rice seeds obtained from the farm of Yezin Agricultural University were soaked in water for 24 h and then incubated at 25˚C for 48 h. The sprouted seeds were sown on a well-prepared seed bed using the wet bed method of the International Rice Research Institute. The water level was gradually increased depending on the seedling height. On day 23, the seedlings were transplanted to hills with a spacing of 20 × 20 cm and two seedlings per hill. During the growing season, irrigation as well as insect, disease, and weed control were performed according to standard cultural practices. The plants were harvested at crop maturity, ~92 days after transplantation, in both seasons.

2.6. N Uptake Analysis of Straw and Grain

Samples obtained from two hills in each plot 2 - 3 cm above ground were oven-dried at 70˚C for 48 h and ground to a fine powder. The N contents of the straw and grain in the samples were analyzed separately using the Kjaldehl distillation method [42] and a Gerhardt Vapodest 20 S (Gerhardt, Apparate GmbH & Co. KG, Germany) at the DAR. Total NU was calculated as the sum of the products of the biomass and the straw and grain concentrations and expressed as $kg \cdot ha^{-1}$.

2.7. Computation of NUE and Related Parameters

The amount of applied N from the inorganic fertilizer and the organic manures was calculated. Based on the total NU of rice plants, NUE [47] was calculated as follows:

Table 1. Chemical compositions of different organic manures for field experiments.

No.	Sample	Moisture (%)	Organic carbon (%)	Total % (oven dry basic)			
				N	P_2O_5	K_2O	S
1.	Cowdung manure	18.54	13.39	1.05	1.99	2.34	0.59
2.	Poultry manure	33.03	24.73	2.83	4.90	4.67	0.53
3.	Vermicompost	28.10	13.91	1.29	0.42	0.70	0.28

Source: Soil and Plant Analysis Laboratory, Soil Science Section, Soil Science, Water Utilization and Agricultural Engineering Division, Department of Agricultural Research (DAR).

$$\text{NUE} = \frac{\text{Grain yield}\left(\text{kg}\cdot\text{ha}^{-1}\right)}{\text{Applied N}\left(\text{kg}\cdot\text{ha}^{-1}\right)}.$$

and the internal efficiency (IE) [48] as:

$$\text{IE} = \frac{\text{Grain yield}\left(\text{kg}\cdot\text{ha}^{-1}\right)}{\text{Total N uptake}\left(\text{kg}\cdot\text{ha}^{-1}\right)}.$$

Agronomic N use efficiency (AUE) [49] was defined as:

$$\text{AUE} = \frac{\text{Grain yield in N fertilized plot} - \text{Grain yield in N control plot}\left(\text{kg}\cdot\text{ha}^{-1}\right)}{\text{Applied N in N fertilized plot}\left(\text{kg}\cdot\text{ha}^{-1}\right)}.$$

The NRE [50] was calculated as follows:

$$\text{NRE}(\%) = \frac{\text{N uptake in N fertilized plot} - \text{N uptake in N control plot}\left(\text{kg}\cdot\text{ha}^{-1}\right)}{\text{Applied N in N fertilized plot}\left(\text{kg}\cdot\text{ha}^{-1}\right)} \times 100.$$

2.8. Statistical Analysis

The data were evaluated using an analysis of variance. Means comparison among treatments were subjected to Tukey's HSD test at the 5% probability level. The analyses were carried out using STATISTIX 8 software (Analytical Software, Tallahassee, FL, USA).

3. Results

3.1. Soil Analysis

The physicochemical properties of the surface (0 - 15 cm) soil at the experimental site are shown in Table 2. The experimental soil was slightly acidic (pH 6.6) under yearly rice cultivation, with a low level of organic matter (1.8%) and a low CEC (8 $cmol_{(+)}$/kg). There were moderate levels of available N (73 mg·kg^{-1}) and available P (20 mg·kg^{-1}), but a low level of available K (77 mg·kg^{-1}). An evalua-

Table 2. Physical and chemical properties of the surface (0 - 15 cm) profile of soil at the experimental site.

Characteristics	Value	Rating
pH (1:5 soil-water)	6.6	Neutral
Available N (mg·kg^{-1})	73.0	Medium
Available P (mg·kg^{-1})	20.0	Medium
Available K (mg·kg^{-1})	77.0	Low
Organic matter (%)	1.8	Low
CEC ($cmol_{(+)}$/kg)	8.0	Low
Texture, % silt, % sand, % clay	19.64, 72.57, 7.79	
Soil textural class	Sandy loam	

Source: Soil and Plant Analysis Laboratory, Soil Science Section, Soil Science, Water Utilization and Agricultural Engineering Division, Department of Agricultural Research (DAR).

tion of the soil data based on a previous report of the Federal Ministry of Agriculture and Natural Resources [51] showed that the soil (sandy loam) was of poor quality.

3.2. Effect of the Combined Application of Organic and Inorganic Fertilizers on NU

The differences in NU as a function of inorganic fertilizer level and organic manure type were significant ($p < 0.01$). The interaction effect of the combined application of organic and inorganic fertilizers was significantly higher ($p < 0.01$) during the dry than the wet season (**Table 3**).

During the dry season, NU was highest (162.21 kg·ha^{-1}) in the combined 100% inorganic fertilizer + poultry manure plot (I_{100}-O_p) (**Figure 2(a)**). A similar NU level (143.83 kg·ha^{-1}) was determined in the 100% inorganic fertilizer + vermicompost plot (I_{100}-O_v) and in the 75% inorganic fertilizer + poultry manure plot (I_{75}-O_p, 146.65 kg·ha^{-1}). NU was lower (140.22 kg·ha^{-1}) in the 100% inorganic fertilizer + cow manure plot (I_{100}-O_c) but higher than achieved with inorganic fertilizer alone (I_{100}-O_0, 116.85 kg·ha^{-1}). With 50% NPK, NU of 136.11 kg·ha^{-1} was achieved in combination with poultry manure (I_{50}-O_p) was similar to that obtained with I_{75}-O_c, I_{100}-O_c, and I_{100}-O_v. By contrast, a decrease in the amount of chemical fertilizer could not be compensated by vermicompost (I_{75}-O_v, 116.28 kg·ha^{-1}; I_{50}-O_v, 116.83 kg·ha^{-1}). However, NU in the I_{75}-O_c and I_{50}-O_c subplots (140.15 and 126.36 kg·ha^{-1}, respectively) was higher than in the combined vermicompost subplots for both I_{75} and I_{50}. In the complete absence of inorganic fertilizer, optimal NU was not achieved with cow manure, poultry manure, or vermicompost (85.00, 98.72, and 90.00 kg·ha^{-1}, respectively).

The trends in the NU during the wet season were similar (**Figure 2(b)**), with the highest value achieved with I_{100}-O_p (137.23 kg·ha^{-1}), followed by I_{75}-O_p (130.97 kg·ha^{-1}) and I_{50}-O_p (130.09 kg·ha^{-1}). When half the amount of inorganic fertilizer was used (I_{50}), poultry manure provided a similar NU to that determined with I_{100}-O_p (137.23 kg·ha^{-1}). Lower values were achieved with I_{100}-O_c (124.71 kg·ha^{-1}), I_{75}-O_c (122.44 kg·ha^{-1}), and I_{50}-O_c (121.68 kg·ha^{-1}) but the NU of the cow manure-treated subplots was consistently higher than that of the

Table 3. Probability values using ANOVA of nitrogen use efficiency and related parameters of hybrid rice (Palethwe-1) in both season (dry and wet season), 2015.

Source	Probability *p* value									
	Dry season (2015)					Wet season (2015)				
	NU	NUE	IUE	AUE	NRE	NU	NUE	IUE	AUE	NRE
Inorganic fertilizer (I)	<0.0001	0.0001	<0.0001	0.0040	0.0006	<0.0001	0.0001	0.0063	0.0034	0.0617
Organic manures (O)	<0.0001	0.0026	0.1637	0.0001	<0.0001	<0.0001	0.0575	0.0001	ns	0.0010
I × O	0.0001	0.0018	<0.0001	0.0004	0.0006	0.0001	ns	0.0001	ns	ns
CV %	4.88	7.70	9.11	13.77	10.16	5.87	7.11	5.71	16.77	12.14

NU = Nitrogen uptake, NUE = nitrogen use efficiency, IUE = internal use efficiency, AUE = agronomic nitrogen use efficiency, NRE = nitrogen recovery efficiency, ns = non-significant difference.

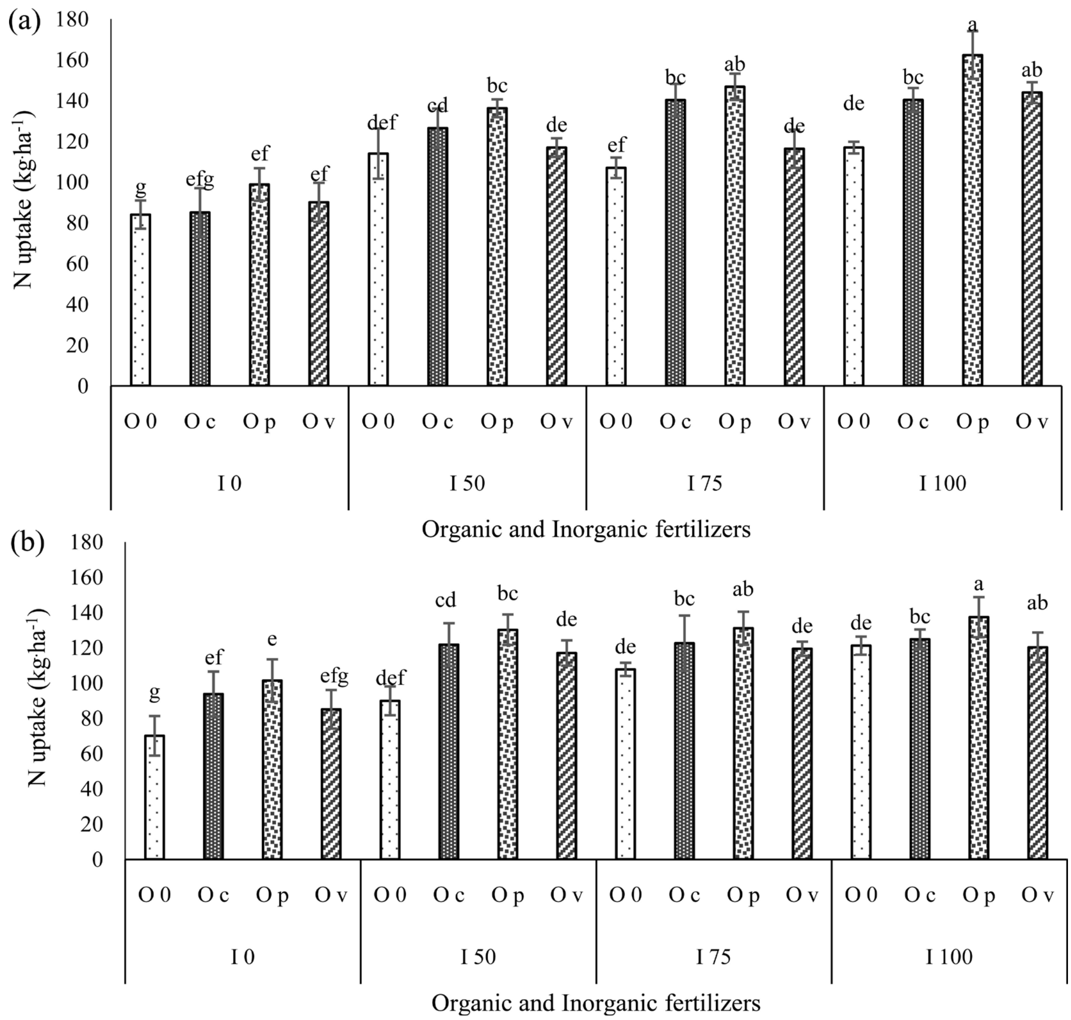

Figure 2. Nitrogen uptake of hybrid rice (Palethwe-1) as affected by combined application of organic manures and inorganic fertilizers in (a) dry season and (b) wet season, 2015. The histograms with the same letter are not significantly different by the Tukey HSD test ($p < 0.05$). The bar on each histogram indicates standard deviation. The numbers followed by I show the percentage of NPK applied based on 150 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1} and 120 kg K_2O ha^{-1}. I = Inorganic fertilizer; O_c = cow manure, O_p = poultry manure and O_v = vermicompost.

O_v-treated subplots, even at the highest inorganic fertilizer level (I_{100}-O_v, 120.13 kg·ha^{-1}).

3.3. Effect of the Combined Application of Organic and Inorganic Fertilizers on NUE

In both seasons, the differences in NUE among inorganic fertilizer levels and among organic manures were significant ($p < 0.01$ and $p < 0.05$, respectively) (Table 3). As the amount of inorganic fertilizer increased, the NUE of the subplots treated with combined organic and inorganic fertilizer decreased (Figure 3(a) and Figure 3(b)). At 50% NPK, the highest NUE value of 104.13 kg grain ha^{-1} (kg N applied)$^{-1}$ was obtained with I_{50}-O_p, with similar efficiencies of 102.93 and 101.65 kg grain ha^{-1} (kg N applied)$^{-1}$ measured in the I_{50}-O_c and I_{50}-O_v subplots, respectively (Figure 3(a)). NUEs were lower in the I_{75}-O_c, I_{75}-O_p, and

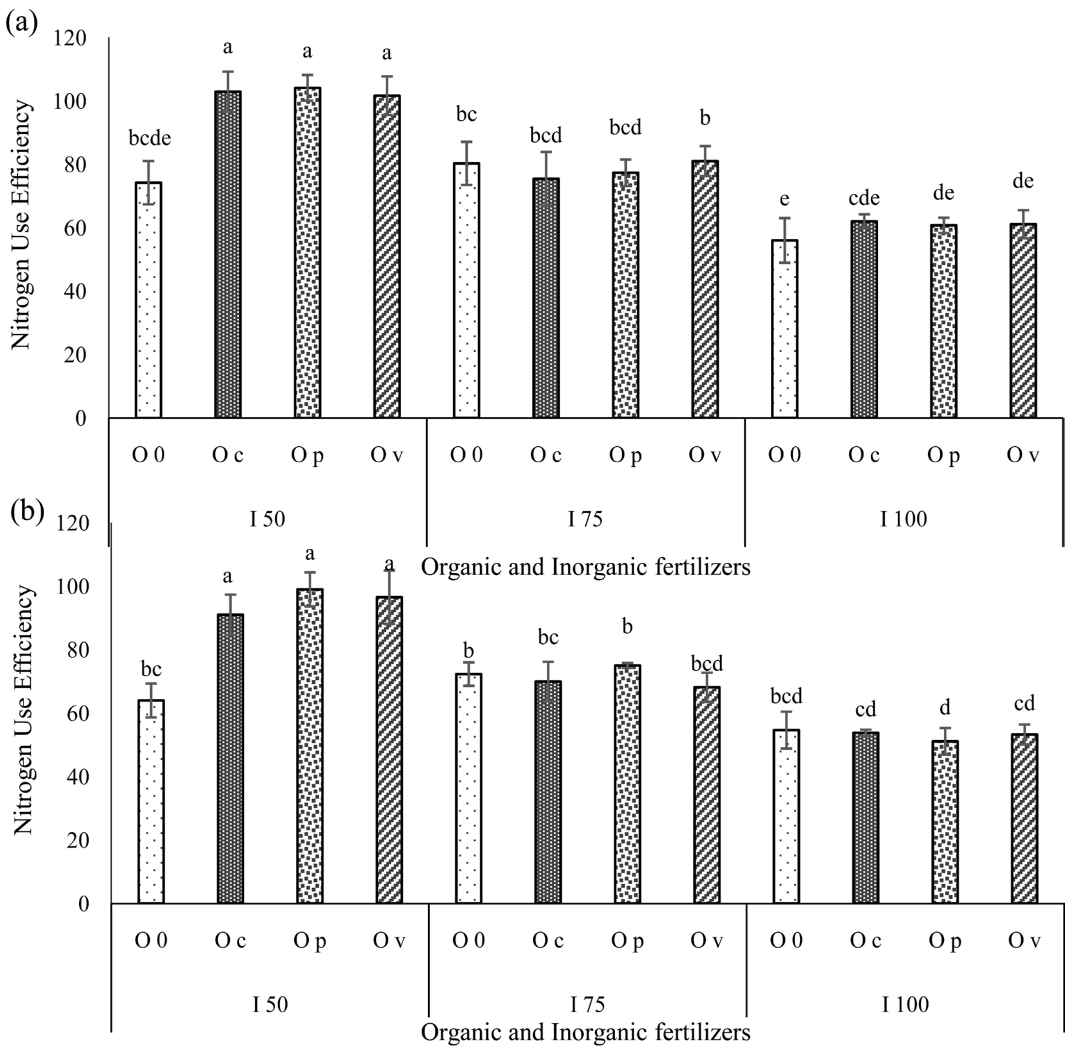

Figure 3. Nitrogen use efficiency of hybrid rice (Palethwe-1) as affected by combined application of organic manures and inorganic fertilizers in (a) dry season and (b) wet season, 2015. The histograms with the same letter are not significantly different by the Tukey HSD test ($p < 0.05$). The bar on each histogram indicates standard deviation. The numbers followed by I show the percentage of NPK applied based on 150 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1} and 120 kg K_2O ha^{-1}. I = Inorganic fertilizer; O_c = cow manure, O_p = poultry manure and O_v = vermicompost.

I_{75}-O_v subplots [75.45, 77.34, and 81.02 kg grain ha^{-1} (kg N applied)$^{-1}$, respectively], but also lower in the I_{75}-O_0 subplot [80.30 kg grain ha^{-1} (kg N applied)$^{-1}$]. The application of any of the manures in combination with 100% NPK during the dry season resulted in NUEs that were lower than those of any of the other tested conditions.

During the wet season, all of the NUEs obtained in the combined applications of organic and inorganic fertilizer were very similar to those of the dry season. The highest NUE was that of the I_{50}-O_p subplot [99.00 kg grain ha^{-1} (kg N applied)$^{-1}$] followed by the I_{50}-O_v [96.51 kg grain ha^{-1} (kg N applied)$^{-1}$] and I_{50}-O_c [91.00 kg grain ha^{-1} (kg N applied)$^{-1}$] subplots. The NUE achieved with the various combinations of organic and inorganic fertilizer correlated negatively with the amount of applied inorganic fertilizer (Figure 3(b)).

3.4. Effect of the Combined Application of Organic and Inorganic Fertilizers on the IE

The IE, defined as the grain yield per total N uptake, was significantly ($p < 0.01$) influenced by both organic and inorganic fertilizer application during both seasons. The interaction between organic and inorganic fertilizers was also significant (Table 3). The highest IE value was 73.37 kg grain (kg NU)$^{-1}$ in the I_{50}-O_v subplot, followed by 71.88, 68.23, 69.40, 71.90, 70.12, and 67.65 kg grain (kg NU)$^{-1}$ in the I_{50}-O_p, I_{50}-O_c, I_{75}-O_p, I_{100}-O_0, I_{100}-O_c, and I_{100}-O_v subplots, respectively, with higher, albeit similar grain yields per increasing NU. The IE values in fields treated only with inorganic fertilizer decreased gradually with decreasing amounts of NPK, from 71.90 kg grain (kg NU)$^{-1}$ in the I_{100}-O_0 subplot, to 60.00 and 48.88 kg grain (kg NU)$^{-1}$ in the I_{75}-O_0 and I_{50}-O_0 subplots, respectively. In the presence of 50% NPK, the grain yields (kg) per NU (kg) obtained with I_{50}-O_p, I_{50}-O_c, and I_{50}-O_v were similar to those of I_{75} and I_{100} plus any of the organic manures (Figure 4(a)).

During the wet season, the IE of the I_{50}-O_p subplots was also the highest [85.00 kg grain (kg NU)$^{-1}$], with a slightly lower value in I_{75}-O_p subplots [76.00 kg grain (kg NU)$^{-1}$]. An increase in the amount of inorganic fertilizer to I_{75} and I_{100} resulted in similar yields in the fields treated with the organic manures (Figure 4(b)). The IEs of O_c and O_v were the same in both seasons regardless of the inorganic fertilizer level.

3.5. Effect of the Combined Application of Organic and Inorganic Fertilizers on AUE

The AUE was significantly influenced by inorganic fertilizer application ($p < 0.01$) during both seasons, but was influenced by organic manure only during the dry season (Table 3). The maximum AUE [62.62 kg additional grain yield (kg N applied per·ha)$^{-1}$] was achieved in the I_{50}-O_p subplot, but with similar values of 56.25 and 55.37 kg additional grain yield (kg N applied per·ha)$^{-1}$ determined in the I_{50}-O_c and I_{50}-O_v subplots, respectively. A 50% NPK application alone resulted in a lower AUE [I_{50}-$O_{0,}$ 22.22 kg additional grain yield (kg N applied per·ha)$^{-1}$]. As the amount of applied N from inorganic fertilizer and organic manures increased, the AUE decreased gradually, due to the similar yields among I_{50}, I_{75}, and I_{100} subplots treated with the different manures. The lowest AUE was that of the I_{100} plus manures subplot, because of the high inputs of N from both organic and inorganic fertilizers vs. the grain yield (Figure 5(a)). The overall trends in the AUE during the wet season were the same, with the highest value in the I_{50}-O_p subplot [45.00 kg additional grain yield (kg N applied per·ha)$^{-1}$] followed by 40.00 and 39.95 kg additional grain yield (kg N applied per·ha)$^{-1}$ for the I_{50}-O_c and I_{50}-O_v subplots, respectively (Figure 5(b)).

3.6. Effect of the Combined Application of Organic and Inorganic Fertilizers on the NRE

The application of inorganic fertilizer significantly influenced the NRE, both during the dry ($p < 0.01$) and the wet ($p < 05$) seasons. The differences in the NRE achieved with the different manures were also significant ($p < 0.01$). The NRE was highest in the I_{50}-O_p subplot [51.25 kg additional NU (kg N applied)$^{-1}$] but the differences compared to the other subplots were not significant with values of 45.63, 43.66, 44.61, and 43.95 kg additional NU (kg N applied)$^{-1}$ for I_{50}-O_c, I_{75}-O_c, I_{75}-O_p, and I_{100}-O_p, respectively. Generally, the NRE decreased steadily with increasing amounts of N from organic and inorganic fertilizers. In the sandy loam soil, the high losses of N in I_{100}-O_c, I_{100}-O_p, and I_{100}-O_v resulted in lower NREs of 32.96, 43.95, and 35.08 kg additional NU (kg N applied)$^{-1}$, re-

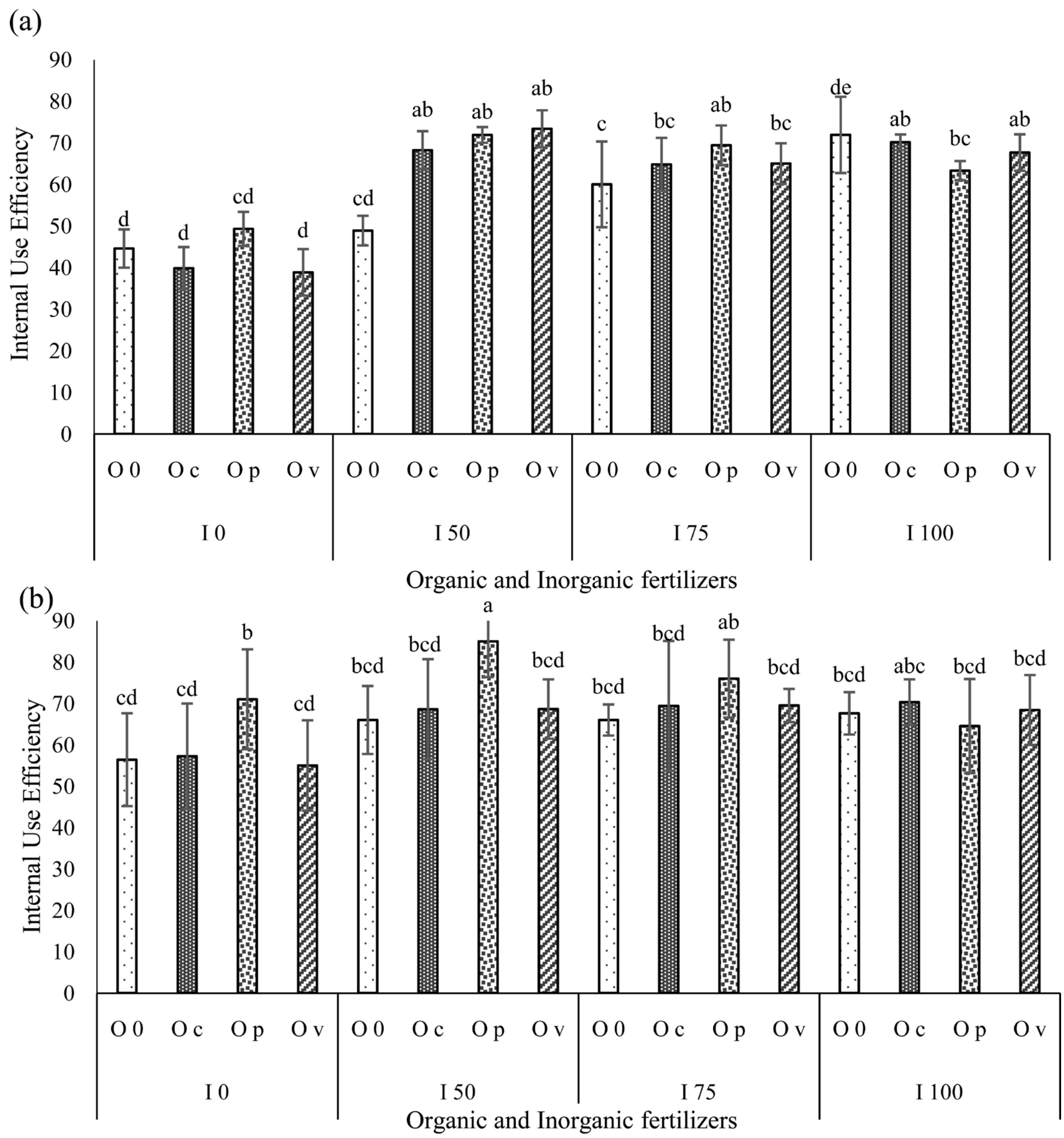

Figure 4. Internal use efficiency of hybrid rice (Palethwe-1) as affected by combined application of organic manures and inorganic fertilizers in (a) dry season and (b) wet season, 2015. The histograms with the same letter are not significantly different by the Tukey HSD test ($p < 0.05$). The bar on each histogram indicates standard deviation. The numbers followed by I show the percentage of NPK applied based on 150 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1} and 120 kg K_2O ha^{-1}. I = Inorganic fertilizer; O_c = cow manure, O_p = poultry manure and O_v = vermicompost.

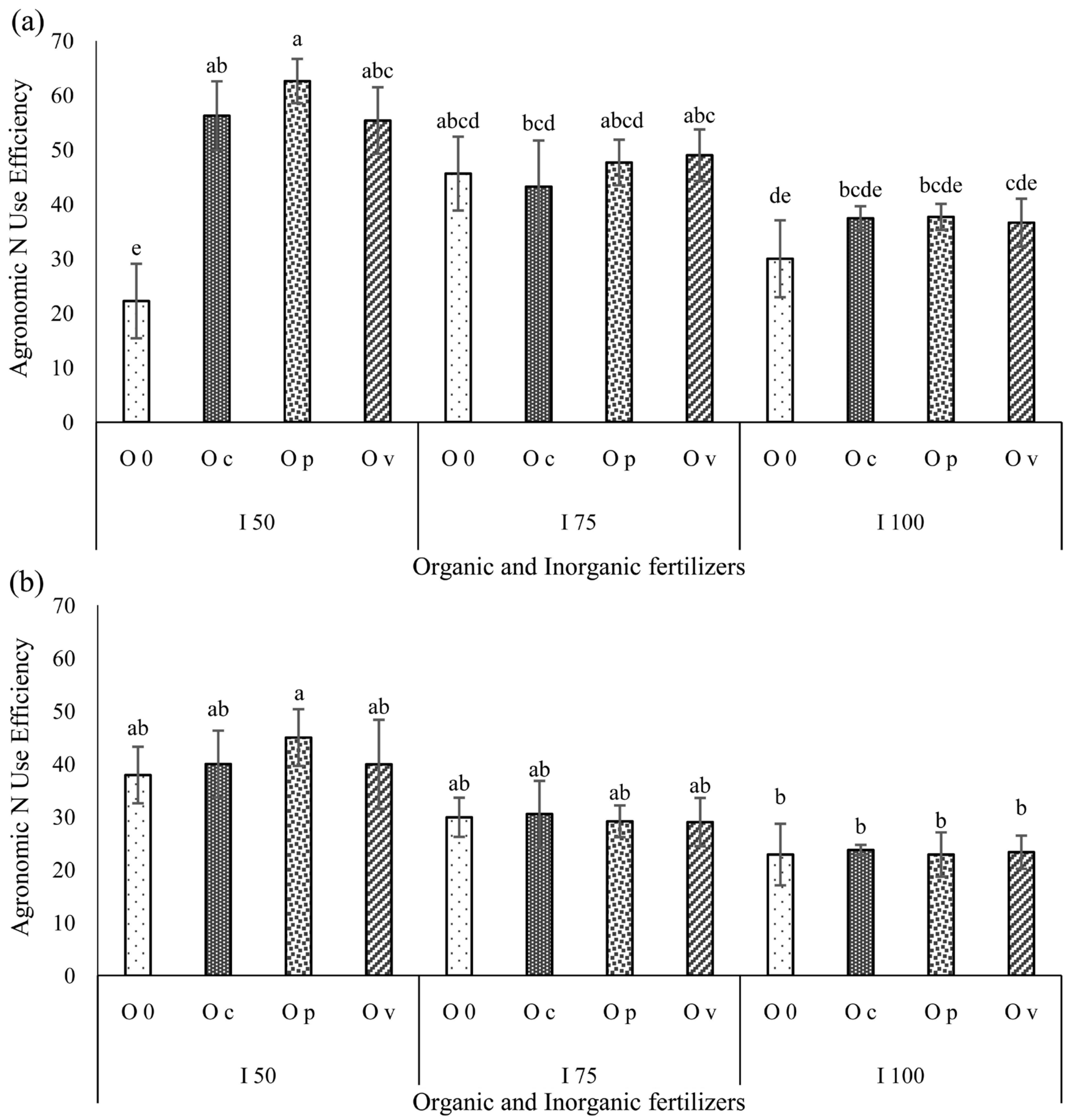

Figure 5. Agronomic N use efficiency of hybrid rice (Palethwe-1) as affected by combined application of organic manures and inorganic fertilizers in (a) dry season and (b) wet season, 2015. The histograms with the same letter are not significantly different by the Tukey HSD test ($p < 0.05$). The bar on each histogram indicates standard deviation. The numbers followed by I show the percentage of NPK applied based on 150 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1} and 120 kg K_2O ha^{-1}. I = Inorganic fertilizer; O_c = cow manure, O_p = poultry manure and O_v = vermicompost.

spectively) (Figure 6(a)).

During the wet season, the highest NUE was also in the I_{50}-O_p subplot [48.06 kg additional NU (kg N applied)$^{-1}$], in accordance with its higher NU. Nonetheless, similar NREs of 43.98 and 37.96 kg additional NU (kg N applied)$^{-1}$ were obtained in the I_{50}-O_c and I_{50}-O_v subplots, respectively. Because of the high N losses, the NREs in the I_{75} plus manures and I_{100} plus manures subplots were lower. In the subplots treated with 100% inorganic fertilizer alone, the NRE was lower [24.11 kg additional NU (kg N applied)$^{-1}$] than in the I_{50}-O_p [48.06 kg additional NU (kg N applied)$^{-1}$] subplot (Figure 6(b)).

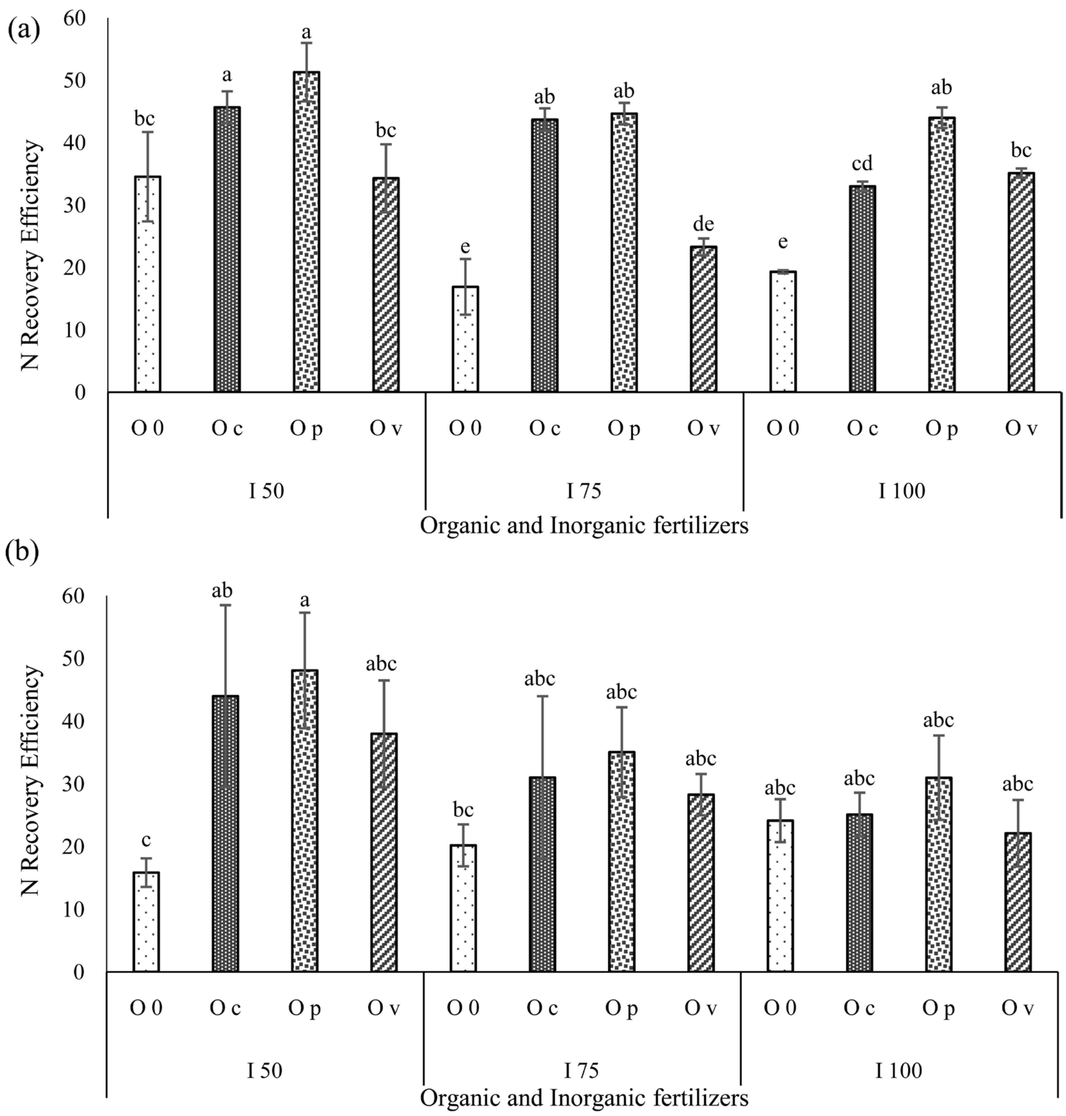

Figure 6. Nitrogen recovery efficiency of hybrid rice (Palethwe-1) as affected by combined application of organic manures and inorganic fertilizers in (a) dry season and (b) wet season, 2015. The histograms with the same letter are not significantly different by the Tukey HSD test ($p < 0.05$). The bar on each histogram indicates standard deviation. The numbers followed by I show the percentage of NPK applied based on 150 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1} and 120 kg K_2O ha^{-1}. I = Inorganic fertilizer; O_c = cow manure, O_p = poultry manure and O_v = vermicompost.

4. Discussion

4.1. Beneficial Effects of Combined Inorganic and Organic Fertilizer Application

This study compared the effect of inorganic fertilizer application, as recommended by Myanmar's DAR for the hybrid rice variety Palethwe-1 (150 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1}, 120 kg K_2O ha^{-1}), with that of the combined application of organic and inorganic fertilizers in terms of NU, NUE, and related parameters. Generally, hybrid rice with a high yield potential has high nutrients requirements. However, the use of large amounts of inorganic fertilizers, including N fertilizers [52], alone causes high losses and a low recovery of N, especially in sandy loam soil such as that of the study site. These high N losses lead not only to a low NUE but also to environmental pollution and high costs to farmers.

Our study showed that the combined application of organic and inorganic fertilizer effectively enhances the NUE of hybrid rice, as the maximum NUE was achieved in the I_{50}-O_p subplot in both seasons. The higher NU achieved with I_{50}-O_p resulted in a larger yield, as a high NUE was generated with less N loss, presumably due to the higher nutrient availability and major nutrient content of O_p. In fact, this manure had the highest nutrient content of all tested manures. Its use as a soil amendment for agricultural crops was previously shown to provide appreciable quantities of all important plant nutrients [53]. The application of organic manure not only increases NU through mineralization but also reduces N losses from the soil [54]. However, in this study, the NUEs for I_{50}-O_c and I_{50}-O_v were generally lower than the NUE of $O_{p,}$ due to their lower NPK content. In this study, as the amount of inorganic fertilizer was increased, the NUE of each combined application steadily decreased, with a very low NUE recorded in the I_{100}-O_0 subplot. This result was consistent with the previously reported low NUE of chemical N fertilizer due to heavy losses [55]. By contrast, Xu *et al.* [56] reported a higher NUE following the combined application of organic and inorganic fertilizers than with chemical fertilizers alone. In fact, the yields obtained in the I_{50}, I_{75}, and I_{100} subplots to which manures were added did not differ substantially. A similar trend was seen in terms of NU, with the maximum value occurring with I_{100}-O_p, which suggested that the use of O_p with chemical fertilizer can minimize N losses. However, with 100% inorganic fertilizer alone, NU was low and N losses were high, resulting in yields lower than those achieved with I_{100}-O_p, I_{100}-O_c, and I_{100}-O_v. Myint *et al.* [57] concluded that the high level of plant available nutrients in organic manure was a product of slow nutrient release throughout the growing season. Liu *et al.* [58] reported that the combined application of organic and inorganic fertilizers improved the NUE of fertilizer N and reduced N losses; however, in the subplots without inorganic fertilizer (I_0-O_c, I_0-O_p, and I_0-O_v), NU in both seasons was low, which demonstrated that organic manure alone cannot provide optimum NU and high grain yields. This finding is in agreement with that of Bair [59], who found that for sustainable crop production higher crop yields were not possible using organic manure alone.

4.2. Correlations between Applied N and N Accumulation in the Treated Subplots

The correlation coefficient (R^2) between applied N and N accumulation among the subplots treated with organic and inorganic fertilizer was significant ($p <$ 0.05) (Table 4). In both seasons, applied N correlated positively with N accumulation for each combined application, especially in the O_p subplot, in which the strongest the correlation was measured for both the dry and the wet season. Generally, the NU of applied manures depends on their mineralizable N content, which together with the nutrient content is higher in poultry manure than in

Table 4. Regression equations and coefficients of determination between applied N ($kg \cdot ha^{-1}$) and N uptake ($kg \cdot ha^{-1}$) of hybrid rice (Palethwe-1) as affected by combined application of organic and inorganic fertilizers in both season (dry and wet season), 2015.

	Inorganic fertilizers	Cow manure	Poultry manure	Vermicompost
Dry season	$y = 0.1777x + 91.399$ $R^2 = 0.678^*$	$y = 0.2506x + 104.85$ $R^2 = 0.8331^{**}$	$y = 0.4196x + 92.555$ $R^2 = 0.9614^{**}$	$y = 0.2074x + 101.66$ $R^2 = 0.6426^*$
Wet season	$y = 0.241x + 80.535$ $R^2 = 0.7243^{**}$	$y = 0.2099x + 96.117$ $R^2 = 0.5223^*$	$y = 0.2538x + 95.484$ $R^2 = 0.7514^{**}$	$y = 0.343x + 74.523$ $R^2 = 0.7429^{**}$

y = N accumulation ($kg \cdot ha^{-1}$), x = Applied N ($kg \cdot ha^{-1}$), **indicates significance at $p = 0.01$, *indicates significance at $p = 0.05$.

cow manure or vermicompost [60].

However, in the subplots receiving inorganic fertilizer alone, the correlation between applied N and N accumulation was relatively weak, reflecting N losses from the sandy loam soil. Together, these results recommend the use of combined applications of organic and inorganic fertilizer, especially O_p, to maximize NU and therefore the yield of hybrid rice (Palethwe-1).

The IE of Palethwe-1 hybrid rice was highest in the I_{50}-O_p subplot, because of the higher grain yield and higher NU. With the application of increasing amounts of inorganic fertilizer, the IE decreased, as the yields of the manure-treated I_{50}, I_{75}, and I_{100} subplots were similar. The lower NU of the O_c and O_v subplots accounted for their lower IEs, which were still higher than the IE in the subplots treated with inorganic fertilizer alone (I_{50}-O_0, I_{75}-O_0, and I_{100}-O_0). Liu *et al.* [61] also reported that the integrated use of organic waste and chemical fertilizer was more effective than either one alone.

A lower AUE was obtained only for 100% inorganic fertilizer alone whereas the values with I_{100}-O_c, I_{100}-O_p, and I_{100}-O_v were similar. Although the amount of applied N from organic and inorganic fertilizer was maximized, the yields of the different subplots were similar. Thus, half the amount of inorganic fertilizer resulted in the maximum AUE in both seasons when poultry manure was also applied. This result demonstrates that the maximum yield of hybrid rice depends on the application of the optimal amount of applied N from organic as well as inorganic fertilizer. In addition to N, organic manure provides important micronutrients and increases the CEC of soil, which in turn improves nutrient availability and, in combination with inorganic fertilizers, enhances plant growth and grain yield [62]. The higher grain yield associated with the higher NU correlated with the higher recovery efficiency of the applied N. The high NRE of the I_{50}-O_p subplot may have been due to the delayed the conversion of organic N to mineralizable N, leading to slow N release and a better match between the N supply and demand of hybrid rice. Poultry manure acts as a slow-release fertilizer, supplying nutrients, especially N, on a continuous basis throughout the growing season [63]. However, with the combined application of I_{75} and I_{100} and O_p, O_c, or O_v, high N losses were incurred. A decrease in the nutrient recovery percentage with increasing levels of fertilizer application was also reported by Culley *et al.* [64], Motavalli *et al.* [65], and Cusick *et al.* [66], and low NRE in rice plants treated with cow manure was reported by Uenosono *et al.* [67] and Nishida *et al.* [68], among others.

5. Conclusion

In our experiments, 5 t·ha^{-1} of each manure (cow manure, poultry manure, and vermicompost) was combined with different amounts of inorganic fertilizer. Both cow and poultry manures are readily available in Myanmar and are thus economical for the country's farmers. The use of vermicompost is less wide spread because of inadequate production and the high cost. Efficient and inexpensive methods of organic and inorganic fertilizer application are important for Myanmar farmers. Our results demonstrate that 50% inorganic fertilizer applied in combination with manures, especially poultry manure, is sufficient to provide high but economical hybrid rice yields. Specifically, in the central dry zone of Myanmar, the use of I_{50} (75 kg N ha^{-1}) + O_p (5 t poultry manure ha^{-1}) will greatly enhance the NU, NUE, and NRE of hybrid rice. If poultry manure is not easily available, cow manure (5 t·ha^{-1}) plus I_{75} (112.5 kg N ha^{-1}) is the next best alternative for reducing chemical fertilizer use. Antil and Singh [69] also reported that the application of organic manures, such as cow or poultry manure, in conjunction with mineral fertilizer was very effective in sustaining crop productivity. Moreover, the integrated use of organic and inorganic fertilizers also has environmental benefits, as it reduces both chemical fertilizer usage and N losses, and allows for sustainable crop production [70]. Further evaluation of the different available manures and their interactions with inorganic fertilizers, together with the development of new rice varieties, will lead to continued improvements in rice production throughout the world.

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Conflict of Interest: Disclosure Statements

I have disclosed that there are no conflicts of interest regarding publication of this article.

References

[1] FAO (2013) FAOSTAT. Food and Agricultural Organization. Viale delle Terme di Caracalla 00153, Rome, Italy. http://www.fao.org/faostat/en/#home

[2] Baligar, V.C. and Bennett, O.L. (1986) Outlook on Fertilizer Use Efficiency in the Tropics. *Fertilizer Research*, **10**, 83-96. https://doi.org/10.1007/BF01073907

[3] Baligar, V.C. and Bennett, O.L. (1986) NPK-Fertilizer Efficiency—A Situation Analysis for the Tropics. *Fertilizer Research*, **10**, 147-164.

[4] Chung, R.S., Wang, C.H., Wang, C.W. and Wang, Y.P. (2000) Influence of Organic Matter and Inorganic Fertilizer on the Growth and Nitrogen Accumulation of Corn Plants. *Journal of Plant Nutrition*, **23**, 297-311. https://doi.org/10.1080/01904160009382017

[5] FAO (2003) Sustainable Rice Production for Food Security. *Preceding of the 20th*

Session of the International Rice Commission Bangkok, Thailand, 23-26 July 2002. Plant Production and Protection Division, Food and Agriculture Organization, Viale delle Terme di Caracalla 00100, Rome, Italy.
http://www.fao.org/documents/card/en/c/702ceb2b-0aaf-5233-a6b6-43ddef0712b3/

[6] Ohajianya, D.O. and Onyenweaku, C.E. (2002) Farm Size and Relative Efficiency in Rice Production in Ebonyi State, Nigeria. *Modeling Simulation Controlling and Development*, **23**, 1-16.

[7] Hadden, R.L. (2008) The Geology of Burma (Myanmar): An Annotated Bibliography of Burma's Geology, Geography and Earth Science. Topographic Engineering Center, US Army Corps of Engineers, Alexandria, Virginia, 312 p.

[8] Peng, S.B., Buresh, R.J., Huang, J.L., Zhong, X.H., Zou, Y.B., Yang, J.C., Wang, G., Liu, Y., Hu, R. and Tang, Q. (2010) Improving Nitrogen Fertilization in Rice by Site-Specific N Management. A Review. *Agronomy for Sustainable Development*, **30**, 649-656. https://doi.org/10.1051/agro/2010002

[9] Cao, Y.S., Tian, Y.H., Yin, B. and Zhu, Z.L. (2013) Assessment of Ammonia Volatilization from Paddy Fields under Crop Management Practices Aimed to Increase Grain Yield and N Efficiency. *Field Crops Research*, **147**, 23-31.

[10] Hu, R.F., Cao, J.M., Huang, J.K., Peng, S.B., Huang, J.L., Zhong, X.H., Zou, Y., Yang, J. and Buresh, R.J. (2007) Farmer Participatory Testing of Standard and Modified Site-Specific Nitrogen Management for Irrigated Rice in China. *Agricultural Systems*, **94**, 331-340.

[11] Yang, Y.C., Zhang, M., Li, Y.C., Fan, X.H. and Geng, Y.Q. (2012) Controlled Release Urea Improved Nitrogen Use Efficiency, Activities of Leaf Enzymes, and Rice Yield. *Soil Science Society of America Journal*, **76**, 2307-2317.
https://doi.org/10.2136/sssaj2012.0173

[12] Chao, X., Wu, L.H., Ju, X.T. and Zhang, F.S. (2005) Role of Nitrification Inhibitor DMPP (3,4-Dimethylpyrazole Phosphate) in NO_3-N Accumulation in Greengrocery (*Brassica campestris* L. ssp *chinensis*) and Vegetable Soil. *Journal of Environmental Sciences* (*China*), **17**, 81-83.

[13] Zhu, G., Peng, S., Huang, J., Cui, K., Nie, L. and Wang, F. (2016) Genetic Improvements in Rice Yield and Concomitant Increases in Radiation- and Nitrogen-Use Efficiency in Middle Reaches of Yangtze River. *Scientific Reports*, **6**, Article No. 21049. https://doi.org/10.1038/srep21049

[14] Wen, Z.H., Shen, J.B., Blackwell, M., Li, H.G., Zhao, B.Q. and Yuan, H.M. (2016) Combined Applications of Nitrogen and Phosphorus Fertilizers with Manure Increase Maize Yield and Nutrient Uptake via Stimulating Root Growth in a Long-Term Experiment. *Pedosphere*, **26**, 62-73.

[15] Glaser, B., Lehman, J., Fuhrboter, M., Solomon, D. and Zech, W. (2001) Carbon and Nitrogen Mineralization in Cultivated and Natural Savanna Soils of Northern Tanzania. *Biology and Fertility of Soils*, **33**, 301-309.
https://doi.org/10.1007/s003740000324

[16] Kramer, A.W., Doane, T.A., Horwath, W.R. and Kessel, C.V. (2002) Combining Fertilizer and Inorganic Inputs to Synchronize N Supply in Alternative Cropping Systems in California. *Agriculture*, *Ecosystems & Environment*, **91**, 233-243.

[17] Satyanarayana, V., Prasead, P.V.V., Murthy, V.R.K. and Rodty, K.J. (2002) Influence of Combined Application of Farm Yard Manure and Inorganic Fertilizers on Yield Components of Irrigated Lowland Rice. *Journal of Plant Nutrition*, **25**, 2081-2090. https://doi.org/10.1081/PLN-120014062

[18] Jobe (2003) Integrated Nutrient Management for Increased Rice Production in the Inland Valleys of the Gambia. In: Sanyang, S., Ajayi, A. and Sy, A.A., Eds., *Pro-*

ceedings of the Second Biennial Regional Rice Research Review, WARDA Proceedings Series No. 2, 1, 35-41.

[19] Narwal, R.P. and Chaudhary, M. (2006) Effect of Long-Term Application of FYM and Fertilizer N on Available P, K and S Content of Soil. 18*th World Congress of Soil Science*, Philadelphia, Pennsylvania, 9-15 July 2006.

[20] Ramalakshmi, Ch.S., Rao, P.C., Sreelatha, T., Mahadevi, M., Padmaja, G., Rao, P.V. and Sireesha, A. (2012) Nitrogen Use Efficiency and Production Efficiency of Rice under Rice-Pulse Cropping System with Integrated Nutrient Management. *Journal of Rice Research*, **5**, 42-51.

[21] Zadeh, A.N. (2014) Effects of Chemical and Biological Fertilizer on Yield and Nitrogen Uptake of Rice. *Journal of Biodiversity and Environmental Sciences*, **4**, 37-46.

[22] Adeoye, G.O., Ojobor, S.A. and Adeoluwa, O.O. (2004) Evaluation of Potential of Co-Compost of Rice-Wastes, Cowdung and Poultry Manure for Production of Rice. In: Salako, F.K., Addetunji, M.T., Ojanuga, A.G., Arowolo, T.A. and Ojeniyi, S.O., Eds., *Managing Soil Resources for Food and Security and Sustainable Environment: Proceedings of the* 29*th Annual Conference of the Soil Science Society of Nigeria*, 213-218.

[23] Khanam, M., Rahman, M.M., Islam, M.R. and Islam, M.R. (2001) Effect of Manures and Fertilizers on the Growth and Yield of BRRI Dhan 30. *Pakistan Journal of Biological Sciences*, **4**, 172-174. https://doi.org/10.3923/pjbs.2001.172.174

[24] Mitchell, C.C. and Tu, S. (2006) Nutrient Accumulation and Movement from Poultry Litter. *Soil Science Society of America Journal*, **70**, 2146-2153. https://doi.org/10.2136/sssaj2004.0234

[25] Tejada, M. and Gonzalez, J.L. (2008) Application of Two Vermicomposts on a Rice Crop: Effects on Soil Biological Properties and Rice Quality and Yield. *Agronomy Journal*, **101**, 336-344. https://doi.org/10.2134/agronj2008.0211

[26] Hossaen, M.A., Shamsuddoha, A.T.M., Paul, A.K., Bhuiyan, M.S.I. and Zobaer, A.S.M. (2011) Efficacy of Different Organic Manures and Inorganic Fertilizer on the Yield and Yield Attributes of Boro Rice. *The Agriculturists*, **9**, 117-125.

[27] Yang, J.P., Jiang, N. and Cheng, J. (2003) Dynamic Simulation of Nitrogen Application Level Effects on Rice Yield and Optimization Analysis of Fertilizer Supply in Paddy Field. *Chinese Journal of Applied Ecology*, **14**, 1654-1660. (In Chinese)

[28] De Datta, S.K., Magnaye, C.P. and Moomaw, J.C. (1968) Efficiency of Fertilizer Nitrogen (^{15}N-Labelled) for Flooded Rice. 9*th International Soil Sciences Congress*, Adelaide, Australia, 4, 67-76.

[29] Prasad, R. and Power, J.F. (1995) Nitrification Inhibitors in Agriculture, Health and Environment. *Agronomy Journal*, **54**, 231-281.

[30] Duxbury, J.M., Abrol, I.P., Gupta, R.K. and Bronson, K. (2000) Analysis of Long-Term Soil Fertility Experiments with Rice-Wheat Rotation in South Asia. In: Abrol, I.P., Bronson, K., Duxbury, J.M. and Gupta, R.K., Eds., *Long-Term Soil Fertility Experiments in Rice-Wheat Cropping System*, *Rice-Wheat Consortium Res. Ser. No.* 6, *Rice-Wheat Consortium for the Indo-Gangetic Plains*, New Delhi, India, 7-22.

[31] Ladha, J.K., Fisher, K.S., Hossain, M., Hobbs, P.R. and Hardy, B. (2000) Improving the Productivity and Sustainability of Rice-Wheat Systems of the Indo-Gangetic Plains: A Synthesis of NARS-IRRI Partnership Research. Discussion Paper No. 40, IRRI, Los Banos, Philippines, 1-31.

[32] Yadav, R.L., Dwivedi, B.S. and Pandey, P.S. (2000) Rice-Wheat Cropping System: Assessment of Sustainability under Green Manuring and Chemical Fertilizer Inputs. *Field Crops Research*, **65**, 15-30.

[33] Prasad, R. (2005) Organic Farming Vis-à-Vis Modern Agriculture. *Current Science*,

89, 252-254.

[34] Barker, R., Herdt, R.W. and Rose, B. (1985) The Rice Economy in Asia. Resources for the Future, Inc., Washington DC, 324 p.

[35] Rayment, G.E. and Higginson, F.R. (1992) Australian Laboratory Handbook of Soil and Water Chemical Method. Reed International Books Australia P/L, Trading as Inkata Press, Port Melbourne, 330 p.

[36] Hussain, F. and Kauser, A.M. (1985) Evaluation of Alkaline Permanganate Method and Its Modification as an Index of Soil Nitrogen Availability. *Plant and Soil*, **84**, 279-282. https://doi.org/10.1007/BF02143191

[37] Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. (1954) Estimation of Available Phosphorus in Soil Extraction with Sodium Bicarbonate. USDA Circ. 939. U.S. Government Printing Office, Washington DC.

[38] Muramoto, J., Goto, I. and Ninaki, M. (1992) Rapid Analysis of Exchangeable Cations and Cation Exchange Capacity (CEC) of Soils by Shaking Extraction Method. *Journal of Soil Science and Plant Nutrition*, **63**, 210-215.

[39] Kononova, M.M. (1966) Soil Organic Matter; Its Nature, Its Role in Soil Formation and in Soil Fertility. Pergamon Press Ltd., Oxford, NY.

[40] Liu, C.L., Wang, M.K. and Yang, C.C. (2001) Determination of Cation Exchange Capacity by One-Step Soil Leaching Column Method. *Communications in Soil Science and Plant Analysis*, **32**, 2359-2372. https://doi.org/10.1081/CSS-120000378

[41] Nelson, D.W. and Sommers, L.E. (1996) Total Carbon, Organic Carbon, and Organic Matter. In: Sparks, D.L., *et al.*, Eds., *Methods of Soil Analysis*, *Part* 3, *Chemical Methods*, SSSA Book Series No. 5, SSSA and ASA, Madison, WI, 961-1010.

[42] Kjeldahl, J. (1883) Neue Methode zur Bestimmung des Stickstoffs in organischen Körpern. *Zeitschrift für analytische Chemie*, **22**, 366-382. https://doi.org/10.1007/BF01338151

[43] Kitson, R.E. and Mellon, M.G. (1944) Colorimetric Determination of Phosphorus as Molybdivanadophosphoric Acid. *Industrial and Engineering Chemistry*, *Analytical Edition*, **16**, 379-383.

[44] Stevenson, A.E. and Langen, H.D. (1960) Measurement of Feed Intake by Grazing Cattle and Sheep VII. Modified Wet Digestion Method for Determination of Chromic Oxide in Feces. *New Zealand Journal of Agricultural Research*, **3**, 314-319. https://doi.org/10.1080/00288233.1960.10418086

[45] Raghavan, R. (1991) A Rapid Turbidimetric Method for the Determination of Total Sulphur in Zinc Concentrate. *Talanta*, **38**, 525-528.

[46] Walter, E. and Dean, J.R. (1974) Determination of Carbonate and Organic Matter in Calcareous Sediments and Sedimentary Rocks by Loss on Ignition: Comparison with Other Methods. *Journal of Sedimentary Petrology*, **44**, 242-248.

[47] Peng, S., Garcia, F.V., Laza, R.C., Sanico, A.L., Visperas, R.M. and Cassman, K.G. (1996) Increased N-Use Efficiency Using a Chlorophyll Meter on High-Yielding Irrigated Rice. *Field Crop Research*, **47**, 243-252.

[48] Witt, C., Dobermann, A., Abdulrachman, S., Gines, H.C., Guanghuo, W., Nagarajan, R., Satawatananont, S., Son, T.T., Tan, P.S., Tiem, L.V., Simbahan, G.C. and Olk, D.C. (1999) Internal Nutrient Efficiencies of Irrigated Lowland Rice in Tropical and Subtropical Asia. *Field Crop Research*, **63**, 113-138.

[49] Novoa, R. and Loomis, R.S. (1981) Nitrogen and Plant Production. *Plant and Soil*, **58**, 177-204. https://doi.org/10.1007/BF02180053

[50] Dilz, K. (1988) Efficiency of Uptake and Utilization of Fertilizer Nitrogen by Plants. In: Jenkinson, D.S. and Smith, K.A., Eds., *Nitrogen Efficiency in Agricultural Soils*,

Elsevier Applied Sciences, London, 1-26.

[51] FPDD (1990) Literature Review on Soil Fertility Investigation in Nigeria. Federal Ministry of Agriculture and Natural Resources, Lagos, Nigeria.

[52] Liu, X., Wang, H., Zhou, J., Hu, F., Zhu, D., Chen, Z. and Liu, Y. (2016) Effect of N Fertilization Pattern on Rice Yield, N Use Efficiency and Fertilizer-N Fate in the Yangtze River Basin, China. *PLoS ONE*, **11**, e0166002. https://doi.org/10.1371/journal.pone.0166002

[53] Sims, J.T. and Wolf, D.C. (1994) Poultry Waste Management: Agricultural and Environmental Issues. *Advances in Agronomy*, **52**, 1-83.

[54] Duan, Y., Xu, M., Gao, S., Liu, H., Huang, S. and Wang, B. (2016) Long-Term Incorporation of Manure with Chemical Fertilizers Reduced Total Nitrogen Loss in Rain-Fed Cropping Systems. *Scientific Reports*, **6**, Article No. 33611. https://doi.org/10.1038/srep33611

[55] Li, Q.K., Zhu, Z.L. and Yu, T.R. (1998) Fertilizer Problems in the Sustainable Development of Agriculture in China. Jiangxi Science and Technology Publishing House, Nanchang, China, 67-70.

[56] Xu, M.G., Zou, C.M., Qin, D.Z., Kazuyuki, Y. and Yasukazu, H. (2002) Transformation and Utilization of Nitrogen in Paddy Soil under Combined Application of Chemical and Organic Fertilizers. *Acta Pedologica Sinica*, **39**, 147-156.

[57] Myint, A.K., Yamakawa, T., Zenmyo, T., Thao, H.T.B. and Sarr, P.S. (2011) Effects of Organic-Manure Application on Growth, Grain Yield, and Nitrogen, Phosphorus, and Potassium Recoveries of Rice Variety Manawthuka in Paddy Soils of Differing Fertility. *Communications in Soil Science and Plant Analysis*, **42**, 457-474. https://doi.org/10.1080/00103624.2011.542223

[58] Liu, C.A., Li, F.R., Zhou, L.M., Zhang, R.H., Yu, J., Lin, S.L., Wang, L.J., Siddique, K.H.M. and Li, F.M. (2013) Effect of Organic Manure and Fertilizer on Soil Water and Crop Yields in Newly-Built Terraces with Loess Soils in a Semi-Arid Environment. *Agricultural Water Management*, **117**, 123-132.

[59] Bair, W. (1990) Characterization of the Environment for Sustainable Agriculture in the Semi-Arid Tropics. In: Singh, R.P., Ed., *Sustainable Agriculture Issues, Perspective and Prospects in Semi-Arid Tropics*, Academic Press, Hyderabad, 90-128.

[60] Eghball, B., Wienhold, B.J., Gilley, J.E. and Eigenberg, R.A. (2002) Mineralization of Manure Nutrients. *Journal of Soil and Water Conservation*, **57**, 470-473.

[61] Liu, J.R., Zhang, D.Y. and Zhou, W. (1990) The Effect of Mixed Application of Organic and Inorganic Fertilizers to Paddy Soil (The Third Report). *Acta Agriculturae Universitis Jiangxiensis*, **12**, 37-42.

[62] Rani, R., Srivastava, O.P. and Rani, R. (2001) Effect of Integration of Organics with Fertilizer N on Rice and N Uptake. *Fertility News*, **46**, 63-65.

[63] He, Z. and Zhang, H. (2014) Applied Manure and Nutrient Chemistry for Sustainable Agriculture and Environment. Springer, Dordrecht, Heidelberg, New York, London. https://doi.org/10.1007/978-94-017-8807-6

[64] Culley, J.L.B., Phillips, P.A., Hoare, F.R. and Patni, N.K. (1981) Soil Chemical Properties and Removal of Nutrients by Corn Resulting from Different Rates and Timing of Liquid Dairy Manure Applications. *Canadian Journal of Soil Science*, **61**, 35-46. https://doi.org/10.4141/cjss81-005

[65] Motavalli, P.P., Kelling, K.A. and Converse, J.C. (1989) First-Year Nutrient Availability from Injected Dairy Manure. *Journal of Environmental Quality*, **18**, 180-185. https://doi.org/10.2134/jeq1989.00472425001800020009x

[66] Cusick, P.R., Kelling, K.A., Powell, J.M. and Muñoz, G.R. (2006) Estimates of Resi-

dual Dairy Manure Nitrogen Availability Using Various Techniques. *Journal of Environmental Quality*, **35**, 2170-2177. https://doi.org/10.2134/jeq2005.0287

[67] Uenosono, S., Nagatomo, M., Takahashi, S., Kunieda, E. and Yamamuro, S. (2004) Evaluation of Nitrogen Availability of Composted Poultry and Sawdust Cattle Manures Labeled with ^{15}N on Paddy Field Rice. *Japanese Society of Soil Science and Plant Nutrition*, **75**, 313-319.

[68] Nishida, M., Moriizumi, M. and Tsuchiya, K. (2005) Changes in the N Recovery Process from ^{15}N-Labeled Swine Manure Compost and Rice Bran in Direct-Seeded Rice by Simultaneous Application of Cattle Manure Compost. *Soil Science and Plant Nutrition*, **51**, 577-581. https://doi.org/10.1111/j.1747-0765.2005.tb00067.x

[69] Antil, R.S. and Singh, M. (2007) Effects of Organic Manures and Fertilizers on Organic Matter and Nutrients Status of the Soil. *Archives of Agronomy and Soil Science*, **53**, 519-528. https://doi.org/10.1080/03650340701571033

[70] Khan, A.R., Sarkar, S., Nanda, P. and Chandar, D. (2001) Organic Manuring through *Gliricidia maculata* for Rice Production. International Centre for Theoretical Physics (UNESCO and IAEA), Trieste, Italy Int. Rep. IC/IR/2001, 10, 1-4.