Nitrogen

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Boosting Crop Growth Rates of Hybrid Rice (Pukhraj) through Synergistic Use of Organic Nitrogen Sources in Conjunction with Urea Nitrogen

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Abstract: In Northwestern Pakistan's rice-based cropping systems, the prevalent reliance on inorganic nitrogen fertilizers (INF) has led to insufficient nitrogen (N) contributions from soil organic manures (OM). This study aims to evaluate the impact of organic sources (OS), including animal manures (AM) and crop residues (CR), on crop growth rates (CGR) in a rice-wheat rotation. A two-year field experiment involving hybrid rice (*Oryza sativa* L., Pukhraj) was conducted in Batkhela, Khyber Pakhtunkhwa. Various OS and inorganic-N (urea) combinations were applied, emphasizing their influence on CGR. The findings highlight poultry manure (PM) application as the most impactful on CGR, while wheat straw (WS) application resulted in the lowest CGR among the six OS investigated. Additionally, the use of AM showcased superior CGR compared to CR. In the initial year, the highest CGR occurred, with 75% of N sourced from urea and 25% from OS. In the second year, a balanced 50% N application from each source yielded the highest CGR. Urea and PM demonstrated the most robust CGR among OS combinations, while urea and WS yielded the lowest. Notably, onion leaves, a cost-effective option, delivered promising results comparable to berseem residues, indicating their potential as organic manure, especially in sulfur-deficient soils. These findings underscore the viability of onion residue management as a cost-effective alternative to ammonium sulfate fertilizers with global applicability. The abstract recommends promoting organic sources, particularly poultry manure and onion leaves, alongside inorganic-N fertilizers to enhance CGR and reduce dependence on costly alternatives. However, further research and field trials are necessary to explore the long-term impacts of these organic sources on soil health, nutrient cycling, and the sustainability of rice-based cropping systems in Northwestern Pakistan and beyond. In conclusion, this study investigates the influence of organic sources on CGR in rice-wheat rotations, emphasizing the superiority of poultry manure and onion leaves. The findings highlight cost-effective alternatives to conventional fertilizers, emphasizing the need for further research to validate long-term sustainability and applicability beyond the study area.

Keywords: rice; organic wastes; urea; nitrogen; sources; ratios; crop growth rate

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1. Introduction

Rice is a vital staple food and one of the major cash crops in Pakistan, ranking third in cultivation and contributing significantly to the country's agricultural sector. It is the primary source of calories for over four billion people globally [1,2]. However, rice yields in the Malakand Division of Khyber Pakhtunkhwa Province, Northwestern Pakistan, remain modest compared to other regions, ranging from 1633 kg ha^{-1} in Lower Dir to 2323 kg ha^{-1} in Swat [3]. Recent studies have highlighted the importance of crop growth rates and analysis in improving rice productivity. For instance, a study by Khan et al. [4] emphasized the significance of monitoring crop growth rates to identify growth-limiting factors and optimize nutrient management practices. Another study by Ahmad et al. [5]

explored the use of advanced crop growth analysis techniques to assess the impact of environmental factors on rice growth and development. These recent findings emphasize the need for comprehensive crop growth analysis to enhance rice yields and address the productivity challenges in rice cultivation.

Nitrogen plays a crucial role in increasing crop yield by supporting various physiological and metabolic processes in plants. It is an essential component of proteins, enzymes, chlorophyll, and nucleic acids, which are vital for plant growth and development. Adequate nitrogen availability promotes vigorous vegetative growth, enhances photosynthesis, and improves nutrient uptake and utilization efficiency. Recent studies continue to emphasize the significance of nitrogen in maximizing crop productivity. For instance, a study by Kant et al. [6] conducted on maize highlighted that nitrogen fertilization significantly increased grain yield by promoting plant biomass accumulation and optimizing photosynthetic activity. Another study by Liu et al. [7] demonstrated that nitrogen application in wheat positively influenced yield components, such as spike length, kernel number per spike, and grain weight. These findings underscore the importance of proper nitrogen management strategies to ensure optimal crop growth and higher yields to ultimately contribute to global food security.

Nitrogen deficiency in rice impedes growth and reduces yield by affecting vital physiological and metabolic processes, such as photosynthesis and protein synthesis. Studies, like those by Fu et al. [8] and Zhao et al. [9], confirm the adverse impact of nitrogen deficiency on plant height, leaf area index, biomass accumulation, and grain yield in rice, emphasizing the need for effective nitrogen management [10,11].

In modern rice-based cropping systems, the imbalanced use of chemical fertilizers results in reduced production, soil depletion, nutrient imbalance, and environmental contamination [12–14]. Organic manures, including Cattle Manure, Poultry Manure, Sheep Manure, Onion leaves, Wheat Straw, and Berseem Straw, offer a cost-effective and sustainable solution [15–20]. Studies by Huang et al. [21], Cong et al. [22] and Dai et al. [23] showcase the benefits of these organic manures, such as improved soil fertility, nutrient availability, and enhanced crop productivity, promoting sustainable agriculture practices and mitigating environmental concerns.

Crop growth rates and analysis are indispensable tools in agriculture, providing insights into crop development, health, and productivity. Monitoring these rates aids in assessing plant vigor and biomass accumulation and predicting yield potential. Research, such as that by Hidayatullah and Amanullah [19], and Amanullah and Hidayatullah [24], emphasizes the importance of growth analysis in evaluating nutrient management practices and optimizing rice growth and yield. By leveraging crop growth rates, farmers and researchers can make informed decisions to enhance productivity, resource utilization, and overall agricultural sustainability.

To explore the influence of varying ratios of crop residues, animal manures, and urea on the growth rates and growth analysis of hybrid rice (Pukhraj), a field experiment was conducted in Batkhela, Northwestern Pakistan, situated in the Malakand Division. The primary objective of the experiment was to evaluate the feasibility and effectiveness of substituting chemical fertilizer N with more economical and efficient alternatives. The study comprehensively examined the impact of these organic manures on multiple facets of rice growth, encompassing soil water-holding capacity, aeration, seed germination, and root development. The overarching goal was to foster sustainable and productive rice cultivation practices in the region.

The findings of this research project yield valuable insights into optimizing nutrient management practices by seamlessly integrating organic manures with chemical fertilizers. This integrated approach proves instrumental in enhancing both crop growth and yield within the rice-based cropping system of Northwestern Pakistan.

2. Materials and Methods

2.1. Site Description

A field experiment was conducted to investigate the impact of organic and inorganic nitrogen fertilizers on rice (*Oryza sativa* L., hybrid Pukhraj) and their residual effects on subsequent wheat (*Triticum aestivum* L., cv. Siran) in a rice-wheat cropping system at Butkhela, Malakand Agency, Northwest Pakistan, during 2011–2012 (year one) and 2012–2013 (year two). Butkhela is situated at 34°37′0″ N and 71°58′17″ E in Degrees Minutes Seconds (DMS) or 34.6167 and 71.9714 in decimal degrees.

The soil at the experimental site is clay loam, slightly alkaline (pH = 7.3), non-saline (ECe = 1.02 dS m^{-1}), moderately calcareous ($CaCO_3$ = 7.18%), with low soil fertility containing minimal organic matter (0.71%), total nitrogen (0.051%), and extractable phosphorus (5.24 mg kg^{-1}) and zinc (0.93 mg kg^{-1}). Weather data for the experimental period are illustrated in Figure 1. Detailed information on the 26 treatment combinations involving various sources and ratios of organic and inorganic nitrogen fertilizers is presented in Table 1.

Table 1. The 26 treatment combinations while using various sources and ratios of organic and inorganic N-fertilizers (120 kg N ha^{-1}) under a rice-wheat system in Northwest Pakistan.

Treatments	Percent N Applied from Urea	Percent N Applied from Organic Sources					
		Cattle	Poultry	Sheep	Onion	Wheat	Berseem
T_1	0	0	0	0	0	0	0
T_2	100	0	0	0	0	0	0
T_3	75	25	0	0	0	0	0
T_4	75	0	25	0	0	0	0
T_5	75	0	0	25	0	0	0
T_6	75	0	0	0	25	0	0
T_7	75	0	0	0	0	25	0
T_8	75	0	0	0	0	0	25
T_9	50	50	0	0	0	0	0
T_{10}	50	0	50	0	0	0	0
T_{11}	50	0	0	50	0	0	0
T_{12}	50	0	0	0	50	0	0
T_{13}	50	0	0	0	0	50	0
T_{14}	50	0	0	0	0	0	50
T_{15}	25	75	0	0	0	0	0
T_{16}	25	0	75	0	0	0	0
T_{17}	25	0	0	75	0	0	0
T_{18}	25	0	0	0	75	0	0
T_{19}	25	0	0	0	0	75	0
T_{20}	25	0	0	0	0	0	75
T_{21}	0	100	0	0	0	0	0
T_{22}	0	0	100	0	0	0	0
T_{23}	0	0	0	100	0	0	0
T_{24}	0	0	0	0	100	0	0
T_{25}	0	0	0	0	0	100	0
T_{26}	0	0	0	0	0	0	100

Where: T_1 = Control where no organic or inorganic nitrogen was applied. T_2 = 100% nitrogen was applied from urea (inorganic N source) only. T_3 to T_8 = 75% nitrogen was applied from urea, and 25% nitrogen was applied from different organic sources (animal manures viz. cattle, poultry, and sheep, crop residues viz. onion, wheat, and berseem residues, respectively). T_9 to T_{14} = 50% nitrogen was applied from urea, and 50% nitrogen was applied from different organic sources. T_{15} to T_{20} = 25% nitrogen was applied from urea, and 75% nitrogen was applied from different organic sources. T_{21} to T_{26} = 100% nitrogen was applied from organic sources only.

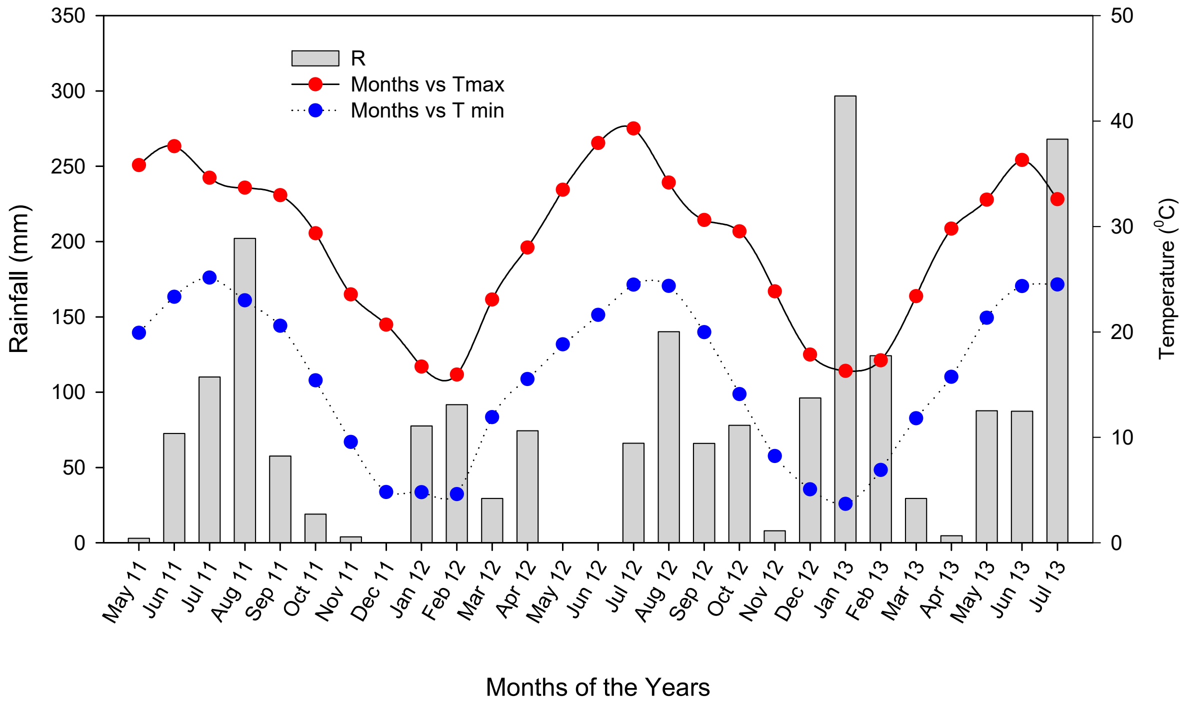

Figure 1. Monthly rainfall (mm), and maximum/minimum temperatures (°C) during the rice growing season in the study area.

2.2. Experimentation

The rice nursery was sown on 5 June, and one-month-old seedlings were transplanted on 5 July in both years. Organic manure was applied 30 days before transplanting, while the required urea was applied in two equal splits, i.e., 50% at transplanting and 30 days after transplanting. Nitrogen at the rate of 120 kg N ha^{-1} was adjusted from fertilizer (urea) after using different sources of organic manures. Nitrogen concentration (%) and C:N ratios of various organic and inorganic nitrogen sources are provided in Table 2.

Table 2. Nitrogen concentration (%) and C:N ratios of various organic and inorganic N sources.

N-Sources	C:N Ratio	Nitrogen (%)
Cattle Manure	18:1	1.1
Poultry Manure	12:1	2.9
Sheep Manure	15:1	1.2
Onion Leaves	17:1	1.2
Wheat Straw	116:1	0.5
Berseem Straw	14:1	1.7

All plots were separated by approximately 30 cm ridges to prevent the movement of water/nutrients among different treatments. Water for each treatment was separately applied from the water channel. The experimental treatments were arranged in a simple randomized complete block design (RCBD) with four replications. The plot size was 12 m^2 (3 m × 4 m), with approximately 300 plants per plot and a plant-to-plant distance of 20 cm apart. A uniform dose of 60 kg P_2O_5 ha^{-1} as triple superphosphate (46% P_2O_5) and 60 kg K_2O ha^{-1} as sulfate of potash (50% K_2O) was applied to all treatments, including the control (no nitrogen applied), during seedbed preparation.

Organic manures were applied 30 days before transplanting, while 50% of the required urea was applied during transplanting, and the remaining 50% was applied 30 days later. All plots treated with N-fertilizers received a total of 120 kg N ha^{-1}, sourced either from exclusive organic or inorganic N sources or through a combination of both (Table 1). Following the rice harvest, a wheat variety (Siren-2010) was planted in October in both years.

2.3. Data Collection

Crop growth rate (CGR) data were collected at three growth stages: transplanting to tillering, tillering to panicle initiation, and panicle initiation to physiological maturity. CGR was calculated based on dry matter accumulation per unit of ground area per unit of time. Table 3 shows a statistical analysis of the data, while Tables 4–6 show mean data combined over the years.

Table 3. Analysis of Variance for Crop Growth Rate of Hybrid Rice "Pukhraj" in Response to Organic and Inorganic N-Fertilizers at Different Growth Stages.

		Level of Significance		
Sources of Variance	**DF**	**TR-TI**	**TI-PI**	**PI-PM**
Years (Y)	1	***	**	***
Blocks (Years)	6	-	-	-
Treatments	25	***	***	*
Control vs. Rest	(1)	***	***	***
Urea vs Pure OS (Organic Sources)	(1)	***	***	ns
Among all OS (Sole + Mixtures)	(23)	***	***	ns
Pure OS vs. Mixtures	[1]	***	***	ns
Pure OS	[5]	***	ns	*
Animal Manures (AM) vs. Crop Residues (CR)	{1}	***	*	**
Mixtures	[17]	***	***	ns
Ratios	{2}	***	***	ns
Organic Sources in Mixtures	{5}	***	***	ns
Ratios × Organic Sources	{10}	ns	ns	ns
Y × Treatments	25	***	ns	ns
Y × Control vs. Rest	(1)	***	ns	**
Y × Urea vs. Pure OS	(1)	***	ns	*
Y × Among all OS	(23)	***	ns	ns
Y × Pure OS vs. Mixtures	[1]	*	ns	**
Y × Pure OS	[5]	ns	ns	ns
Y × AM vs. CR	{1}	ns	ns	ns
Y × Mixtures	[17]	***	ns	ns
Y × Ratios	{2}	***	ns	ns
Y × OS in Mixtures	{5}	*	ns	ns
Y × Ratios × OS	{10}	ns	ns	ns
Error	150	-	-	-
Total	207	-	-	-

Where *, **, *** indicates that data is significant at a 5%, 1%, and 0.1% level of probability, respectively. The word ns stands for the non-significant data. ( ) stands for splits of 25, [ ] stands for splits of 23, and { } stands for splits of 17 and 5 degrees of freedom (DF). Note: TR-TI—Transplanting to Tillering, TI-PI—Tillering to Panicle Initiation, PI-PM—Panicle Initiation to Physiological Maturity.

Table 4. Crop growth rate (g m^{-2} day^{-1}) from transplanting to tillering (TR-TI) of rice hybrid "Pukhraj" as affected by organic and inorganic N-fertilizers.

N Source	2011	2012	Mean
Cattle Manure	3.37	4.55	3.96
Poultry Manure	3.51	4.62	4.06
Sheep Manure	3.40	4.43	3.91
Onion leaves	3.16	4.03	3.60
Wheat Straw	2.70	3.45	3.07
Berseem Straw	3.26	4.13	3.70
Level of Significance	*	***	***
75U:25OS	5.77	6.21	5.99
50U:50OS	5.40	7.28	6.34
25U:75OS	4.60	6.09	5.34

Table 4. *Cont.*

N Source	2011	2012	Mean
Level of Significance	***	***	***
Urea + Organic sources			
Urea + Cattle Manure	5.83	7.04	6.43
Urea + Poultry Manure	6.49	7.42	6.96
Urea + Sheep Manure	5.38	6.82	6.10
Urea + Onion Leaves	4.83	6.20	5.52
Urea + Wheat Straw	4.13	5.24	4.68
Urea + Berseem Straw	4.89	6.43	5.66
Level of Significance	***	***	***
Planned mean comparison			
Control	2.37	2.10	2.24b
Rest	5.10	6.14	5.62a
Urea	7.23	7.34	7.28a
Mixture	5.26	6.53	5.89b
Pure OS	3.23	4.20	3.72b
Mixture	5.26	6.53	5.89a
Urea	7.23	7.34	7.28a
Pure OS	3.23	4.20	3.72b
Animal Manure	5.28	6.45	5.87a
Crop Residues	4.22	5.44	4.83b
Urea	7.23	7.34	7.28a
Pure OS + Mix	4.75	5.94	5.35b
Interactions	Significance	Interactions	Significance
Y × OS	ns	Y × U vs. Mix	***
Y × ratios	***	Y × OS vs. Mix	*
Y × mixtures	*	Y × AM vs. CR	ns
Y × control vs. rest	***	Y × U vs. OS + Mix	***
Y × urea vs. OS	**		

Note: *, **, *** indicates that data is significant at 5%, 1% and 0.1% level of probability, respectively. The word ns stands for the non-significant data at a 5% level of probability. Means followed by different letters in the same category are significantly different at a 5% level of probability.

Table 5. Crop growth rate (g m^{-2} day^{-1}) from tillering to panicle initiation (TI-PI) of rice hybrid "Pukhraj" as affected by organic and inorganic N-fertilizers.

N Source	2011	2012	Mean
Cattle Manure	31.06	35.45	33.26
Poultry Manure	33.51	37.88	35.70
Sheep Manure	31.50	34.86	33.18
Onion leaves	30.00	33.11	31.56
Wheat Straw	26.06	29.92	27.99
Berseem Straw	30.88	33.68	32.28
Level of Significance	ns	ns	ns
75U:25OS	50.93	54.15	52.54
50U:50OS	46.85	50.29	48.57
25U:75OS	43.69	46.93	45.31
Level of Significance	***	***	***
Urea + Organic sources			
Urea + Cattle Manure	48.58	54.12	51.35
Urea + Poultry Manure	57.67	59.76	58.72

Table 5. *Cont.*

N Source	2011	2012	Mean
Urea + Sheep Manure	49.44	52.25	50.85
Urea + Onion Leaves	44.96	46.21	45.58
Urea + Wheat Straw	37.54	41.94	39.74
Urea + Berseem Straw	44.75	48.44	46.59
Level of Significance	***	***	***
Planned mean comparison			
Control	25.76	22.84	24.30b
Rest	45.75	48.43	47.09a
Urea	62.29	60.76	61.53a
Mixture	47.16	50.45	48.81b
Pure OS	30.50	34.15	32.33b
Mixture	47.16	50.45	48.81a
Urea	62.29	60.76	61.53a
Pure OS	30.50	34.15	32.33b
Animal Manure	46.93	50.55	48.74a
Crop Residues	39.06	42.21	40.63a
Urea	62.29	60.76	61.53a
Pure OS + Mix	42.99	46.38	44.69b
Interactions	Significance	Interactions	Significance
Y × OS	ns	Y × U vs. Mix	ns
Y × ratios	ns	Y × OS vs. Mix	ns
Y × mixtures	ns	Y × AM vs. CR	ns
Y × control vs. rest	ns	Y × U vs. OS + Mix	ns
Y × urea vs. OS	ns		

Note: *** indicates that data is significant at 0.1% level of probability. The word ns stands for the non-significant data at a 5% level of probability. Means followed by different letters in the same category are significantly different at a 5% level of probability.

Table 6. Crop growth rate (g m^{-2} day^{-1}) from panicle initiation to physiological (PI-PM) maturity of rice hybrid "Pukhraj" as affected by organic and inorganic N-fertilizers.

N Source	2011	2012	Mean
Cattle Manure	24.80	36.12	30.46
Poultry Manure	28.59	37.16	32.88
Sheep Manure	24.90	33.22	29.06
Onion leaves	19.26	27.75	23.50
Wheat Straw	18.12	24.75	21.44
Berseem Straw	17.92	25.42	21.67
Level of Significance	ns	ns	*
75U:25OS	19.61	35.30	27.46
50U:50OS	20.76	41.47	31.12
25U:75OS	19.25	36.04	27.65
Level of Significance	ns	ns	ns
Urea + Organic sources			
Urea + Cattle Manure	21.75	38.19	29.97
Urea + Poultry Manure	18.60	41.39	30.00
Urea + Sheep Manure	19.88	39.48	29.68
Urea + Onion Leaves	19.62	37.47	28.55
Urea + Wheat Straw	18.20	32.19	25.19
Urea + Berseem Straw	21.20	36.89	29.05
Level of Significance	ns	ns	ns

Table 6. *Cont.*

N Source	2011	2012	Mean
Planned mean comparison			
Control	17.21	14.57	15.89b
Rest	20.51	34.06	27.28a
Urea	20.72	23.11	21.91a
Mixture	19.87	37.60	28.74a
Pure OS	22.26	30.74	26.50a
Mixture	19.87	37.60	28.74a
Urea	20.72	23.11	21.91a
Pure OS	22.26	30.74	26.50a
Animal Manure	21.58	38.64	30.11a
Crop Residues	19.36	33.13	26.25b
Urea	20.72	23.11	21.91a
Pure OS + Mix	20.47	35.89	28.18a
Interactions	Significance	Interactions	Significance
Y × OS	ns	Y × U vs. Mix	ns
Y × ratios	ns	Y × OS vs. Mix	**
Y × mixtures	ns	Y × AM vs. CR	ns
Y × control vs. rest	**	Y × U vs. OS + Mix	*
Y × urea vs. OS	**		

Note: *, **, indicates that data is significant at 5% and 1% level of probability, respectively. The word ns stands for the non-significant data at a 5% level of probability. Means followed by different letters in the same category are significantly different at a 5% level of probability.

2.4. Dry Matter Partitioning

At tillering, the panicle initiation stage, and physiological maturity, five plants within each treatment were harvested. Leaves, stems, and panicles were separated, dried, and weighed by an electronic balance to record data on the dry weight of the leaf, stem, and panicles (no panicles were observed at tillering). Dry weight plant^{-1} at each growth stage was calculated as the sum of the dry weights of the plant components.

2.5. Crop Growth Rate

Crop growth rate (CGR), defined as dry matter accumulation per unit ground area per unit time, was determined at various growth stages (transplanting to tillering, tillering to panicle initiation stage, and panicle initiation stage to physiological maturity) according to the procedures used by Amanullah and Stewart [25].

$$\mathrm{CGR} = \mathrm{W}_2 - \mathrm{W}_1/(\mathrm{GA})\ (\mathrm{t}_2 - \mathrm{t}_1)\ (\mathrm{g\ m}^{-2}\ \mathrm{day}^{-1})$$

W_1 = Dry weight (g) m^{-2} at the beginning of interval; W_2 = Dry weight (g) m^{-2} at the end of interval; $t_2 - t_1$ = The time interval between the two consecutive samplings; GA = Ground area occupied by plants at each sampling.

The findings from this study will provide insights into the effects of organic and inorganic nitrogen fertilizers on hybrid rice growth in the rice-wheat cropping system in Northwestern Pakistan, contributing to the optimization of nutrient management practices for sustainable and productive rice cultivation in the region.

2.6. Statistical Analysis

The statistical analysis for this study employed analysis of variance (ANOVA) combined over the years, with treatment means subjected to comparison through the Least Significant Difference (LSD) test at a significance level of $p < 0.05$ [26]. Comprehensive parameter-specific ANOVAs are presented in Table 3, offering a detailed breakdown of statistical assessments for each studied variable.

There were 26 treatment combinations (T), as shown in Table 1. T_1 = Control where no organic or inorganic nitrogen was applied. T_2 = 100% nitrogen was applied from urea only. T_3 to T_8 = 75% nitrogen was applied from urea, and 25% nitrogen was applied from different organic sources. T_9 to T_{14} = 50% nitrogen was applied from urea, and 50% nitrogen was applied from different organic. T_{15} to T_{20} = 25% nitrogen was applied from urea, and 75% nitrogen was applied from different organic sources. T_{21} to T_{26} = 100% nitrogen was applied from six different organic sources (three animal manures viz. cattle, poultry, and sheep, and three crop residues viz. onion, wheat, and berseem residues, respectively).

Out of the total 26 treatments, there was one control, one sole urea, six sole orogenic sources (OS), and 18 different mixtures combinations between urea + OS also including three different ratios of urea and organic sources [75:25, 50:50, and 25:75]. The detailed ANOVA is shown in the following Table 3.

3. Results

3.1. CGR from Transplanting to Tillering (TR-TI)

Crop growth rate (CGR) from the transplanting to the tillering stage was significantly affected by organic sources (OS) in both years (Y), i.e., in 2011 (year one) and 2012 (year two) and when averaging the two years (years mean) (Table 4). However, the Y × OS interaction had no influence on CGR. According to the average of two years' data, the CGR obtained from applying poultry manure (PM) was the highest (4.06 g m^{-2} day^{-1}), followed by cattle manure (CM) (3.96 g m^{-2} day^{-1}) and sheep manure (SM) (3.91 g m^{-2} day^{-1}), and lowest was recorded with wheat straw (WS) (3.07 g m^{-2} day^{-1}). Although CGR showed a non-significant response to Y × OS, it was generally higher in 2012 than in 2011. In 2011, the CGR ranged between 2.70 (WS) and 3.51 g m^{-2} day^{-1} (PM), while in 2012, it ranged between 3.45 (WS) and 4.62 g m^{-2} day^{-1} (PM). The ratios (R) in 2011, 2012, the mean of two years, and the Y × R interaction had a significant effect on CGR up to tillering (Table 4). The two-year averaged data showed that the use of the ratio of 50U:50OS for N produced higher CGR up to tillering (6.34 g m^{-2} day^{-1}) than the other two ratios. The Y × R interaction indicated that in 2011, the CGR was higher when using a 75U:25OS ratio, but in 2012, the ratio of 50U: 50OS produced the higher CGR up to tillering. The CGR up to tillering increased by 25, 23, and 7% in 2012 over 2011 while using different ratios of 50U: 50OS, 25U: 75OS and 75U: 25OS, respectively. The mixtures (M) in 2011, 2012, the mean of two years, and Y × M had a significant effect on CGR up to tillering (Table 4). The CGR varied significantly between 4.13 (U + WS) to 6.49 g m^{-2} day^{-1} (U + PM) in 2011 and between 5.24 (U + WS) to 7.42 g m^{-2} day^{-1} (U + PM) in 2012.

The average of two years' data showed that N applied as U + PM resulted in substantially higher CGR up until tillering (6.96 g m^{-2} day^{-1}), whereas U + WS resulted in the lowest CGR (4.68 g m^{-2} day^{-1}). Combining U and AM resulted in higher CGR up to tillering than combining U and CR (Table 4), as shown by the Y × M interaction. While U + AM showed a 12–21% increase in CGR from 2011 to 2012, U + CR showed a 20–23% increase in CGR from 2011 to 2012 up until tillering. U + BS yielded a 23% increase in CGR during tillering in 2012 compared to 2011, whereas U + PM yielded a 16% increase. The CGR from planting to tillering was greater in the rest of the plots (N treated plots) compared to the control (N not applied) according to the planned mean comparison. The CGR up to tillering increased by 16% in the rest plots in 2012 compared to 2011, whereas it fell by 10% in the control plots in the same time period, leading to a significant year × (control vs. rest) interaction. Single-urea applications resulted in significantly greater CGR through tillering than mixes. In 2012, the CGR up to tillering was lower in the sole urea plots than in 2011, whereas it was higher in the mix plots by 19% in 2012 than in 2011. This difference indicates a significant year × (U vs. Mix) interaction. Figure 2 shows that application sole U produced higher CGR than the mixture during 2011. However, the mixture produced higher CGR than U in 2012. Tillering CGR was increased more by mixed applications than by pure OS applications. In 2012, the CGR was higher for both pure OS and mixed applications than in 2011. There was a significant Y × (OS vs. M) interaction in 2012 because the CGR up to tillering increased by 22% using pure OS compared to 2011, whereas it increased by 19% using a mixture (Figure 2). The CGR up until tillering was greater when solitary urea was applied as compared to pure OS. There was a substantial Y × (U vs. OS) interaction, as the CGR up to tillering was 22% higher in 2012 than in 2011 when using pure OS but only 1% higher when using solitary urea. There was no statistically significant difference between AM and CR in terms of CGR up until tillering. There was no statistically significant Y × (AM vs. CR) interaction because the CGR up to tillering increased by 18% in 2012 compared to 2011 when using AM but by 21% when using CR. Sole urea was more effective for increasing CGR through tillering than OS + mixes. There was a substantial Y × (U vs. pure OS + mix) interaction in 2012 because the CGR up to tillering increased by 19% with pure OS + mix compared to 2011 but only increased by 1% with solitary urea (Figure 3).

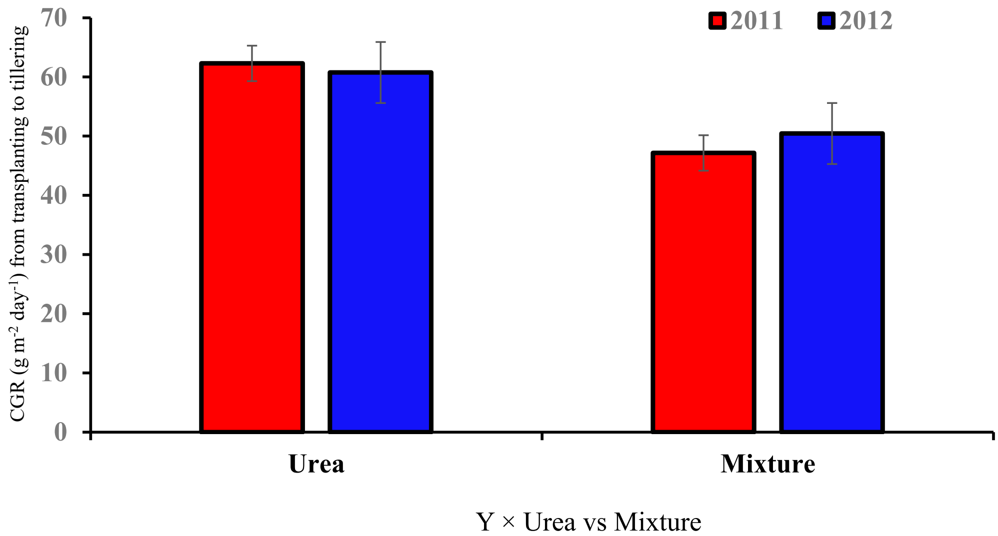

Figure 2. Interactive effect of year × urea vs. mixtures on CGR (g m^{-2} day^{-1}) from transplanting to tillering.

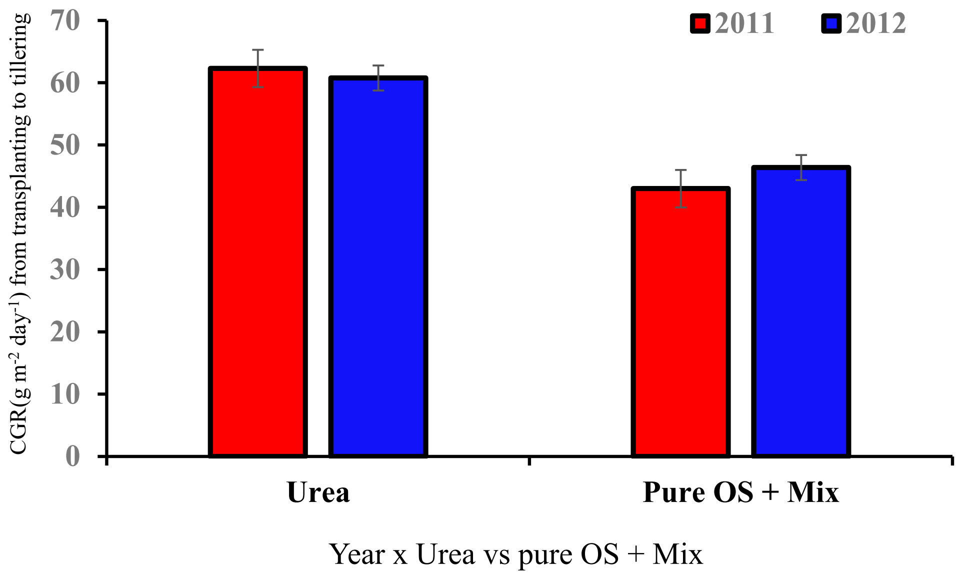

Figure 3. Interactive effect of year × urea vs. pure OS + mixtures on CGR (g m^{-2} day^{-1}) from transplanting to tillering.

3.2. CGR from Tillering to Panicle Initiation (TI-PI)

When considering the two years and the Y × OS interaction, the use of OS had no significant effect on CGR from the tillering to the panicle initiation stage in 2011 and 2012 (Table 4). The two-year average data showed that the application of PM resulted in the highest CGR (35.70 g m^{-2} day^{-1}), while the application of WS resulted in the lowest CGR (27.99 g m^{-2} day^{-1}).

CGR increased from year one to year two despite the lack of a meaningful response to the Y × OS interaction. The CGR varied between 286.06 and 33.51 g per square meter per day in 2011 and between 29.92 and 37.88 g per square meter per day in 2012. CGR was significantly affected by the ratios in 2011 and 2012, as well as by the mean ratio over the years, although the Y × R interaction was not significant (Table 4). Applying the N as 75% from U and 25% from OS resulted in the highest CGR (52.54 g m^{-2} day^{-1}), whereas applying the ratio of 25%U:75%OS resulted in the lowest CGR. Despite the lack of statistical significance between Y and R in terms of CGR, the ratio of 75U:25OS had the highest CGR in both 2012 and 2011. Table 4 shows that the CGR of rice was significantly affected by the mixtures (M) in 2011 and 2012 but not by the two-year mean or the Y × M interaction. In 2011, the CGR ranged from 37.54 (U + WS) to 57.67 (U + PM) g m^{-2} day^{-1}, and in 2012, it was even more extreme, going from 41.94 (U + WS) to 59.76 (U + PM) g m^{-2} day^{-1}. The average of the two years' worth of data showed that the CGR produced by applying N in the form of U + PM was greater than that of the other treatments (58.72 g m^{-2} day^{-1}) but not significantly so. CGR grew more with U + AM than U + CR in both years (Y × M interaction). When U + AM was used, the CGR increase in 2012 over 2011 was between 4 and 10%, whereas when U + CR was used, the CGR increase was between 3 and 10%. CGR was increased by 10% in 2012 over 2011 when using a combination of U + WS and U + CM, whereas it was increased by only 3% when using U + OL. Compared to the control group, the rest (N-treated plots) had better CGR, as determined by the intended mean comparison.

In 2012, the CGR rose by 6% in the uncontrolled plots compared to 2011, whereas it fell by 13% in the controlled plots. The CGR was increased when only urea was used instead of a combination. In 2012, the CGR was down 3% in the solo urea-treated plots compared to 2011, while it was up 7% in the mix plots, leading to a non-significant year × (U vs. Mix) interaction. CGR was increased more by using mixes than by using OS alone. In 2012, the CGR was higher for both pure OS and mixed applications than in 2011. While the CGR increased by 11% in 2012 compared to 2011 while utilizing pure OS, the CGR climbed by just 7% when employing a blend of OS and M, rendering the Y × (OS vs. Mix) interaction insignificant. Urea alone resulted in a greater CGR than olive oil alone.

There was no statistically significant Y × (U vs. OS) interaction because the CGR went up 11% in 2012 compared to 2011 when using pure OS, while it went down 3% when using solo urea. While AM resulted in a slightly greater CGR than CR, the difference was not statistically significant. Using either AM or CR, the CGR rose by 7% in 2012 compared to 2011, and the Y × (AM vs. CR) interaction was not statistically significant. The CGR improved more when only urea was used as opposed to pure OS + mixes. Pure OS + M increased CGR by 7% in 2012 compared to 2011, while single urea lowered CGR by 3% in 2012 compared to 2011. This Y × (U vs. OS + Mix) interaction was not statistically significant.

3.3. CGR from Panicle Initiation to Physiological Maturity (PI-PM)

The mean of the two years of data showed that organic sources had a substantial effect on CGR at PM, while effects from 2011, 2012, and the Y × OS interaction were not statistically significant (Table 5). The two-year average data showed that the CGR acquired with PM application was the highest (32.88 g m^{-2} day^{-1}), followed by CM (30.46 g m^{-2} day^{-1}) and being on par with SM (29.06 g m^{-2} day^{-1}), and the CGR obtained with WS application was the lowest (21.44 g m^{-2} day^{-1}). While there was no statistically significant relationship between CGR and the Y × OS interaction, it was generally greater in 2012 than in 2011.

The CGR varied from 17.92 (BS) to 28.59 (PM) g m^{-2} day^{-1} in 2011 and from 24.75 (WS) to 37.16 (PM) g m^{-2} day^{-1} in 2012. There was no statistically significant relationship between CGR and the ratios (R) in 2011, 2012, the two-year mean, or the Y × R interaction (Table 5). Based on averages over two years, the highest CGR (31.12 g m^{-2} day^{-1}) was achieved with an application of N comprised of 50% urea and 50% organic source (50U:50OS). Using a 50U:50OS N ratio in both years, the CGR was higher in 2011 according to the Y × R interaction. Using N at 50U:50OS, 25U:75OS, and 75U:25OS resulted in a 50, 47, and 44% increase in CGR in 2012 compared to 2011. The effects of the mixtures (Mix) on CGR were not statistically significant (Table 5). Based on the average of two years' data, it was found that the CGR produced by applying N as U + PM was comparable to other combinations (at 30.00 g m^{-2} day^{-1}).

Combining urea with animal manures (U + AM) resulted in a higher CGR than using urea with crop residues (U + CR) (Table 5). When compared to 2011, U + AM led to a CGR increase of between 43% and 55% in 2012. CGR increased by 55% in 2012 compared to 2011 when U + PM was used. According to the planned mean comparison, the CGR produced by the rest of the plots was greater than that of the control. There was a significant Y × (control vs. rest) interaction due to a 20% rise in CGR in the rest plots from 2011 to 2012 and a 15% drop in CGR in the control plots from 2011 to 2012. When compared to applications including both urea and OS, those involving only urea resulted in more CGR. In 2012, compared to 2011, the CGR grew by 1% in the sole urea plots but by 24% overall. However, when compared to using pure OS, CGR was increased when combinations were used. In 2012, the CGR was higher for both pure OS and mixed applications than in 2011.

A significant Y × (OS vs. Mix) interaction was found since the CGR increased by 19% in 2012 compared to 2011 when utilizing pure OS and by 24% when applying a combination (Figure 4). The CGR increased more when sole urea was used as opposed to when alone OS was used. There was a highly significant Y × (U vs. OS) interaction, as the CGR rose by 19% in 2012 compared to 2011 when using only OS but rose by only 1% when using only urea. Although AM resulted in a greater CGR than CR, the difference was not statistically significant. When compared to 2011, CGR with AM climbed by 23% in 2012, while CGR with CR increased by 22% in the same time period. When compared to using pure OS + mixes, the CGR improved when only urea was used. Significant Y × (U vs. OS + Mix) interaction was observed because of the 23% increase in CGR in 2012 over 2011 with OS + Mix and the 1% increase in CGR in 2012 over 2011 with solitary urea (Figure 5).

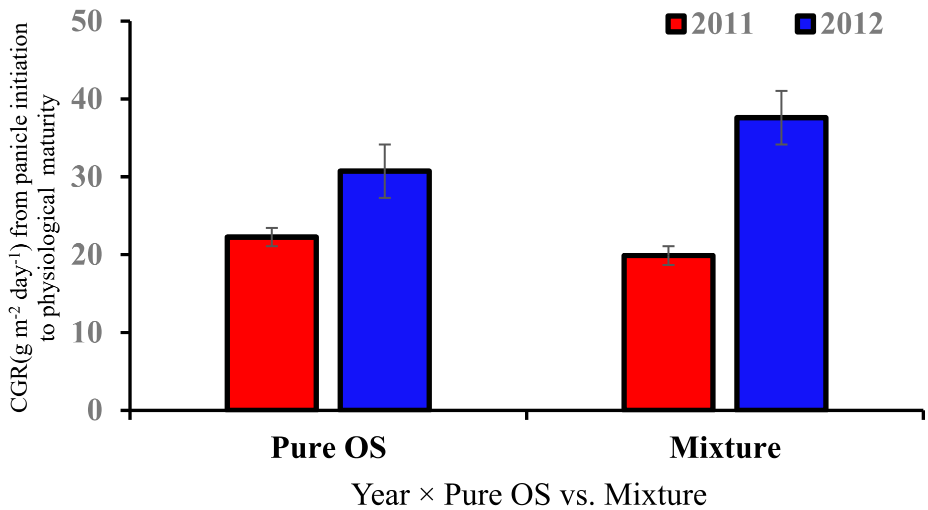

Figure 4. Interactive effect of year × pure OS vs. mix on CGR (g m^{-2} day^{-1}) from panicle initiation to physiological maturity.

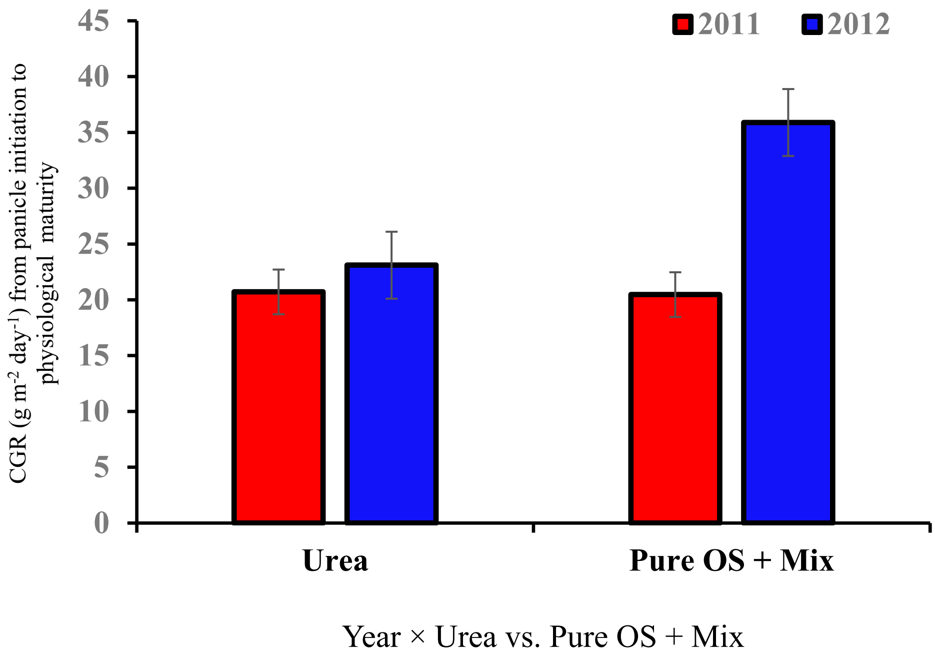

Figure 5. Interactive effect of year x urea vs. pure OS + mix on CGR (g m^{-2} day^{-1}) from panicle initiation to physiological maturity.

4. Discussion

The application of poultry manure as the sole organic manure resulted in increased crop growth rates (CGR) at all three growth stages [CGR from transplanting to tillering (TR-TI), CGR from tillering to panicle initiation (TI-PI), and CGR from panicle initiation to physiological maturity (PI-PM)] as compared to the CGR with other organic sources (OS). However, the CGR at all three growth stages was significantly ($p < 0.05$) reduced when wheat straw (WS) was used alone. The variation in CGR under different organic sources can be explained by the shifts in the C/N ratio that occur when switching between different OS. The application of poultry manure (PM) with its low C/N ratio (12:1) increased CGR, while the application of wheat straw (WS) with its high C/N ratio (116:1) decreased CGR at all growth stages.

Our research reveals that reducing the C/N ratio of organic sources accelerates the decomposition process, leading to increased nutrient availability. This, in turn, fosters the growth and development of rice, ultimately enhancing the CGR in rice. The elevated C/N ratio observed in wheat straw, coupled with its sluggish decomposition in wetland soils (rice fields), plays a significant role in diminishing crop growth rates when utilized in such environments. Organic materials characterized by high C/N ratios, such as cereals (like wheat), are more prone to nitrogen competition with standing crops. This competition often results in nitrogen insufficiency, leading to a substantial reduction in both rice crop growth and development. Consequently, the overall CGR of rice experiences a significant decline under these conditions.

Moreover, submerged soils (rice fields) present challenges in terms of organic matter decomposition. Our findings underscore the potential benefits of composting wheat straw before its application in rice cultivation, showcasing the capacity to enhance both CGR and final yield. Consequently, for wetland rice farming, opting for well-decomposed or low C/N ratio organic manures, such as animal manures, emerges as a preferable and more effective choice than cereal residues. This approach ensures improved nutrient availability and contributes to the overall success of rice cultivation in submerged soil conditions.

Building on prior research, evidence suggests a noteworthy impact on various aspects of rice cultivation when employing high C/N organic sources, specifically wheat residues. Studies indicate a reduction not only in CGR but also in crucial parameters such as plant height [19], yield, and yield components [24]. This reduction is consistently observed across all three distinct growth stages of the rice crop [19]. These findings emphasize the comprehensive influence of high C/N organic sources on multiple facets of rice cultivation, further substantiating the importance of optimizing organic sources for enhanced crop performance and productivity.

On the contrary, when compared with wheat straw, the utilization of low C/N organic sources, particularly animal manures, berseem, and onion residues, demonstrates a noteworthy impact on various aspects of rice cultivation, including plant height [19], overall yield, and yield components [24]. These results align with earlier research conducted by [27,28], reinforcing the notion that enhanced yield attributes contribute to an overarching improvement in crop yield. Our own investigations further substantiate this, revealing that animal manures (AM) emerge as the most efficacious method for augmenting rice yield, primarily by fostering an increased CGR across the plant's developmental stages [24].

Moreover, our study underscores the pivotal role played by animal manures in promoting not only heightened plant stature but also enhanced yield parameters, aligning with the broader theme observed in the works of [27,28]. The observed increase in CGR throughout the developmental phases of the rice plant serves as a key mechanism driving the overall improvement in yield, as elucidated by our findings [24]. The employment of animal manures, especially poultry manure, emerges as a potent strategy for bolstering rice cultivation outcomes, showcasing its multifaceted impact on plant growth, yield, and crucial yield components. These findings not only echo earlier research but also contribute valuable insights into the nuanced dynamics of organic sources in optimizing rice crop production.

The CGR across all three growth stages of rice exhibited a notable increase when nitrogen (N) was applied at a ratio of 75% from urea (U) and 25% from organic sources (OS) during the initial year (75U:25OS). Intriguingly, a shift to a 50% U and 50% OS application in the second year yielded higher CGR at all developmental phases. In 2011, the CGR surpassed that of 2012, potentially attributed to a higher proportion of N from urea and a lower contribution from OS (75U:25OS). Publications stemming from the same study consistently highlight elevated plant height [19], increased yield, and improved yield components [24] associated with the 75U:25OS ratio in the inaugural year. However, the 50U:50OS ratio demonstrated a more favorable impact on CGR at various growth stages in 2012, as indicated by corresponding publications from the study, showcasing augmented plant height, enhanced yield, and improved yield components [24].

Our hypothesis posits that a ratio of 25% U and 75% OS (25U:75OS) could potentially optimize the growth, development, and overall production of the rice crop over time. This conjecture is rooted in the understanding that a higher reliance on organic sources might exert a beneficial influence on the long-term performance of the rice crop. Further exploration of this ratio could offer valuable insights into sustainable and effective nutrient management strategies for rice cultivation. Based on these studies, it can be concluded that OS provides limited benefits in the first year of the rice-based system, but these benefits increase over time in a sustainable manner [19,24].

Our data unearthed compelling insights into the impact of different nitrogen combinations (mixtures) on rice crop performance. Specifically, the amalgamation of urea with animal manures, particularly poultry manure (U + PM), exhibited a pronounced enhancement in CGR across all three growth stages. In stark contrast, the combination of urea and wheat straw (U + WS) was associated with a decrease in CGR throughout the rice plant's developmental phases. Furthermore, our experimental trials demonstrated that the U + PM combination contributed to both increased plant height [19] and enhanced yield [24] for the rice crop. Conversely, the U + WS combination yielded contrasting results, leading to a reduction in both plant height [19] and overall yield [24]. The observed positive effects of U + PM on growth and yield are postulated to be linked, at least in part, to the lower C/N ratio of 12:1 present in poultry manure [19,24].

Corroborating our findings, Hassanuzazzaman et al. [29] reported that the incorporation of poultry manure fosters increased crop development by supplying ample plant nutrients. Notably, the application of U + PM not only optimizes soil conditions for robust plant growth but also increases total rice biomass and dry weights at the time of harvest [30]. In essence, our study highlights the nuanced influence of nitrogen combinations, particularly emphasizing the positive outcomes associated with the strategic use of urea in conjunction with poultry manure. This not only enhances growth and yield but also aligns with sustainable agricultural practices by optimizing nutrient utilization and minimizing environmental impact.

In the first year of the experiment (2011), solitary urea application outperformed the mixture (U + OS) in terms of CGR at different growth stages. Likewise, Myint et al. [15] found that mineral fertilization was superior to organic manures. However, in the second year (2012), the mixture (U + OS) outperformed solitary urea in terms of CGR. Nevertheless, in both years, CGR was higher when N was applied as a mixture (U + OS) compared to using OS alone. These results are in line with our published data from the same study, which confirms that U + OS increased plant height [19], grain yield [24], and total rice biomass [30] as compared to sole organic sources, especially in the first year of our research.

The marked improvement in CGR observed in the second year, resulting from the application of urea combined with organic sources (U + OS), can be attributed to advancements in the dynamics of crop growth and the generation of elevated yield components [24]. This intricate interplay triggers heightened photosynthetic assimilation, leading to an augmented accumulation of dry matter and total rice biomass [30]. This phenomenon is further facilitated by increased soil nitrogen content and enhanced nitrogen uptake by rice plants [31]. These cumulative effects contribute synergistically to an overall increase in CGR across various growth stages. In essence, the application of U + OS over sole OS in the second year acts as a catalyst, fostering a more robust growth trajectory for the crop. This positive outcome is intricately linked to the promotion of key physiological processes, particularly an enhancement in nitrogen uptake, improved nitrogen usage efficiency, and a concurrent decrease in nitrogen loss from the soil [31].

The advantages of U + OS extend beyond the immediate growth dynamics, encompassing the realm of nutrient management and sustainability. Organic manures play a pivotal role in reducing nitrogen losses [32,33], conserving soil nitrogen through the formation of organic mineral complexes, and ensuring a sustained and prolonged supply of nitrogen to rice plants. This, in turn, leads to an overall increase in total nitrogen on a sustainable basis. The combined application of organic and inorganic nitrogen, as represented by U + OS, surpasses the sole application of urea in terms of grain, straw, and biological yields [34,35]. This substantiates the significance of a balanced and integrated approach to nitrogen management, highlighting the positive and sustainable outcomes achieved through the judicious combination of organic and inorganic nitrogen sources.

Within the treated plots (rest), a discernible increase in CGR at various growth stages was evident, underscoring the positive impact of nitrogen application [6,7]. In stark contrast, the control plots (N not applied) experienced a drastic decrease in CGR [8,9]. This stark contrast emphasizes the critical role of nitrogen in shaping the growth dynamics of wetland rice agriculture. The documented benefits of integrated nitrogen management, encompassing both organic and inorganic sources, further underscore the pivotal role nitrogen plays in wetland rice cultivation [36,37]. Numerous studies have highlighted that such integrated approaches significantly contribute to enhanced paddy production [15,16,24,30]. This surge in productivity can be attributed to the positive influence of integrated nitrogen management on a diverse array of yield components [24] and the total biomass of rice [30].

Moreover, the disparities in nitrogen source absorption emerge as influential factors that significantly shape both plant growth and yield potential [17]. Organic manures, in particular, play a multifaceted role in improving growth and rice yield. They accomplish this by making essential nutrients more available to plants over an extended period, curbing nitrogen volatilization into NH3 gas, and augmenting the soil's water-holding capacity [11,15,31]. In essence, the findings underscore the critical importance of a balanced and integrated nitrogen management strategy for wetland rice agriculture. By comprehensively addressing nutrient availability, nitrogen loss, and soil water retention, such an approach not only optimizes crop growth and yield but also contributes to the sustainability and resilience of wetland rice ecosystems.

Recent studies have shown that the combined application of chemical and organic nitrogen fertilizers in a 50:50 ratio can significantly enhance crop growth and crop growth rate, ultimately improving the final yield of rice crops [19,24,30,31]. This integrated approach capitalizes on the benefits offered by both types of fertilizers, synergistically optimizing nutrient availability and utilization. For instance, research by [38] demonstrated that the combined application of urea (chemical fertilizer) and poultry manure (organic fertilizer) in equal proportions resulted in higher plant height, increased tiller production, and improved grain yield in rice. Another study by [39] supported these findings, revealing that the 50:50 ratio of chemical and organic nitrogen fertilizers improved nutrient uptake efficiency, enhanced photosynthesis, and ultimately led to higher rice yields. These findings underscore the importance of integrating chemical and organic nitrogen sources in a balanced ratio to maximize the growth and yield potential of rice crops.

Recent studies have consistently demonstrated that nitrogen-treated plots in rice cultivation exhibit higher growth and yield compared to nitrogen-control plots. These findings emphasize the crucial role of nitrogen fertilization in optimizing rice production. For instance, nitrogen application significantly improved plant height [19,40], tiller production, panicle length, and grain yield in rice [24]. Similarly, a study conducted by [41–47] reported that nitrogen-treated plots exhibited enhanced leaf area index, higher number of productive tillers, increased grain weight, and overall improved rice yield compared to the control plots. These findings highlight the importance of proper nitrogen management in rice farming to ensure optimal crop growth, maximize yield potential, and meet the increasing demand for this essential staple food.

5. Conclusions

In summary, this study addresses critical aspects of hybrid rice cultivation and nutrient management practices, bringing significant findings and implications to light. Restating the problem, the observed decline in crop growth rate in the absence of nitrogen application underscores the pivotal role of nitrogen fertilization in maximizing rice crop productivity.

Summarizing the overall arguments and findings, the differential effects of various organic sources on crop growth rate underscore the importance of considering the carbon-to-nitrogen ratio (C/N ratio) in organic fertilizer selection. Poultry manure, with its lower C/N ratio, emerged as more beneficial for rice growth compared to wheat residue with a higher C/N ratio. Berseem and onion residues exhibited heightened effectiveness in promoting crop growth, suggesting the potential of specific crop residues as organic fertilizers for enhancing rice productivity.

Discussing the implications, the optimization of nitrogen sources is crucial for maximizing crop growth rate. The combination of 75% nitrogen from inorganic sources (urea) and 25% nitrogen from organic sources (crop residues) proved effective in the first year, while a balanced 50% nitrogen contribution from both sources yielded better results in the second year. These findings emphasize the importance of finding the right balance between inorganic and organic nitrogen sources for sustainable and enhanced crop growth.

Moreover, the utilization of onion wastes as organic manure holds promising prospects, particularly in regions with calcareous and sulfur-deficient soils. The sulfur content in onion residues can address sulfur deficiencies, potentially reducing reliance on expensive nitrogen fertilizers like ammonium sulfate. The economic benefits of using onion residues, often readily available at low or no cost, can significantly enhance the income of smallholder farmers.

In light of these findings, we recommend further exploration and validation of organic fertilizer combinations and alternative sources in different agroecological contexts. Research efforts should focus on optimizing nutrient management strategies to achieve sustainable and high-yielding rice production. Additionally, investigations into the long-term effects of organic and inorganic nitrogen sources on soil fertility, nutrient cycling, and environmental sustainability are warranted.

In conclusion, this research illuminates the significance of nitrogen fertilization, organic fertilizer selection, and nutrient management practices for hybrid rice cultivation. The findings offer valuable insights for farmers, policymakers, and researchers, aiming to enhance crop growth rates, yield composition, and overall agricultural sustainability. By harnessing the potential of organic fertilizers and optimizing nitrogen source combinations, it is possible to achieve improved rice crop productivity while minimizing environmental impacts and supporting the economic well-being of farmers worldwide.

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