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Growth, Yield and Nitrogen Use Efficiency of New Rice Variety under Variable Nitrogen Rates

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Abstract

Globally, the current important concern is to minimize nitrogen use in crop culture under climate change condition. The experiment was conducted at Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh during the rainy season of 2014 to assess growth, yield and nitrogen use efficiency of a new rice variety. The new rice variety (BUdhan 1) was treated with six levels of nitrogenous fertilizer in a randomized complete block design replicated three times. The nitrogen levels 0, 20, 40, 60, 80 and 100 kg N ha^{-1} constituted the treatment variables. Results revealed that growth of the new rice variety favored at higher levels of applied nitrogen although it flattened at 80 and 100 kg N ha^{-1}. Preanthesis assimilates reserves contributed to sustaining the yield of the variety which indicated that current photosynthesis was insufficient to support the present yield level. The assimilate remobilization varied from 109.21 to 232.93 g·m^{-2} between the nitrogen levels where the maximum amount of remobilization was observed at 60 kg N ha^{-1}. The highest grain yield (5.36 t·ha^{-1}) was found when the variety was fertilized with 60 kg N ha^{-1}. Application of 60 kg N ha^{-1} also showed the highest nitrogen use efficiency (344.50 kg grain/kg N applied) of the variety. We concluded that application of the intermediate level of nitrogen was economical and environment-friendly for the cultivation of new rice variety.

Keywords

Rice, Variety, Growth, Yield, Nitrogen Use Efficiency

1. Introduction

Rice is grown in over hundred countries and is the primary food for half of the people in the world [1]. World

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population is expected to increase to 8.5 billion by 2025 and to maintain the self-sufficiency in rice, an increase of 2% - 3% per year in rice production had to be maintained within limited land [2]. During past few decades, rice production increased mostly due to adoption of high yielding varieties, increase in irrigated area and use of chemical fertilizers. However, the rate of increase in rice yield is static and if the rate is not possible to increase, severe food shortage is likely to occur in near future. To push up the yield ceiling, sustainable technologies are essential, which are economically viable and environmentally friendly. Cost minimization by saving resources and development of low cost technologies must be considered in rice production. The potential for increased rice production strongly depends on the ability to integrate a better crop management for the different varieties into the existing cultivation system [3]. Among the crop management practices, judicious application of nitrogenous fertilizer is paramount important for yield enhancement of rice.

Nitrogen, however, is the plant nutrient that is most difficult to manage, especially in a flooded soil environment. The efficiency of applied nitrogen is only 30% - 50% [4] and in many cases even less than that proportion [5]. The efficient use of nitrogen is recognized as an important production factor for rice but it has always been a problem to raise the utilization rate of the rice plant and to increase efficiency of absorbed nitrogen for grain production. As nitrogen fertilizer is costly input and its utilization varies from variety to variety, it is important to determine physiology and yield of new variety under variable nitrogen rates. This study, therefore, was aimed to assess growth, productivity and nitrogen use efficiency of new rice variety as affected by different levels of applied nitrogen fertilizers.

2. Material and Methods

2.1. Experimental Site

Field experiment was carried out at the Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh located at 24˚5'N latitude and 90˚16'E longitude. Nearly 26% of the average rainfall (2270 mm) was received from the monsoon during the study period and minimum and maximum temperatures recorded during period of plant growth were 18.1˚C and 34.3˚C respectively. The soil of the experimental site was shallow red terrace under Salna series which is clay in texture [6].

Thirty days old seedlings of new rice variety (BUdhan 1) was established on 12 August 2014 with one seedling per hill on well puddled soil. The seedlings were collected from a rice seed bed. The crop was treated with six levels of nitrogen fertilizer viz. 0, 20, 40, 60, 80 and 100 kg N ha^{-1}. The experiment was laid out in randomized complete block design with three replications. The unit plot size was 4 m × 3 m. Planting configuration was 20 cm × 15 cm where plots and blocks were separated by 0.5 m and 1.0 m, respectively. The crop was fertilized with 40-20-20-8 kg PKSZn ha^{-1} and applied at the time of final land preparation. Nitrogen was applied as per treatments in the form of urea in three equal installments as top dressing. Top dressing of nitrogen was done at 6, 25 and 50 days after the transplanting (DAT). Irrigation, weeding and other agronomic practices were done whenever necessary.

2.2. Data Collection

Data on different growth parameters, yield components and yield were recorded. Plant samples were collected at 10 days interval starting from 15 DAT till maturity. The above ground plant parts were segmented into different components as leaf, stem, leaf sheath and panicle. Leaf area was measured by an automatic leaf area meter (AAM-8, Hayashi Dehnko, Japan) immediately after sampling. The partitioned plant parts were then dried in an oven at 70˚C for 72 hours and weighed. For determination of yield attributes, five hills were selected and number of tiller per hill, number of filled and unfilled grains per panicle and thousand grain weight was measured. The crop was harvested from an area of 4.8 m^2 leaving two rows to avoid border effect. The harvested yield was converted into $t·ha^{-1}$ at 14% moisture content. Based on dry matter accumulated by crop over times, crop growth rate (CGR) and net assimilation rate (NAR) were calculated by formulas described by Watson [7]. Nitrogen was determined following the method of Cataldo *et al.* [8] while nitrogen use efficiency (NUE) was derived according to Miyoshi [9]. All collected data were subjected to MSTAT-C software package to perform analysis of variance (ANOVA) and arithmetic means of the treatments were compared by employing least significant difference (LSD) test.

3. Results and Discussion

3.1. Growth

Growth of new rice variety was ascribed by tiller number, dry matter production, leaf area development, crop growth rate and net assimilation rate under variable nitrogen rates. Data presented in **Table 1** showed that nitrogen fertilization rates exerted significant effect on number of tillers of new rice variety. Number of tillers per hill of rice increased over time by gradual elevation of nitrogen fertilizer up to 45 days of transplanting afterwards showed a falling trend. Nevertheless, maximum numbers of tillers per hill (14.44) was produced at 45 DAT when the crop fertilized with 100 kg N ha^{-1} which was statistically identical to tiller number observed at 80 kg N ha^{-1}. The lowest number of tiller per hill was recorded from control treatment at all sampling dates. Growth promoting effect of N on plant can be explained on the basis of the fact that N supply increases the number and size of meristematic cells which leads to formation of new shoots [10]. Furthermore, N application is known to increase the levels of cytokinin which affects cell wall extensibility [11]. It is therefore, logical to speculate that N was involved directly or indirectly in the enlargement and division of new cells and production of tissues which in turn were responsible for increase in growth characteristics particularly tiller numbers of the new rice variety (**Table 1**). The reduction of tiller number per plant at later growth stage might be due to tiller mortality under intra plant competition for growth resources. These results are in agreement with those obtained by Mesquita and Pinto [12] and Pathan [13].

Results depicted in **Figure 1** indicated that leaf area index (LAI) was affected noticeably with adding nitrogen fertilizers till end of the experiment. Leaf area index progressively increased and achieved its maximum value (4.17) at 45 days after transplanting when fertilized with 100 kg N ha^{-1}. At same planting date, the lowest value (1.90) was recorded at control treatment.

Afterwards, all treatments showed a declining trend in leaf area index of the variety. In case of any plant, leaves are important organs which have an active role in photosynthesis. To achieve high yield, maximization of leaf area is an important factor of the crop [14]. The increasing trend of LAI at higher nitrogen levels (**Figure 1**) can be attributed to the positive effect of nitrogen on both leaf development and leaf area duration of the variety [15] [16]. Progressive increment in LAI of the variety up to certain days may be due to the fact that addition of nitrogen triggers increased number of leaves per plant and expansion of individual leaf. The increase in leaf number as well as size due to enough nutrition can be expected in terms of possible increase in nutrient absorption capacity of the variety through better root development and increased translocation of carbohydrates from source to growing grains [14]. In contrast, the diminishing trend of LAI after flowering might be due to falling of lower leaves. These trends are in agreement with those obtained by Lampayan *et al.* [17], Shibu *et al.* [18] and Azarpour *et al.* [19].

Dry matter production by rice plants increased progressively with the advancement of growth stages and reached rice peak at maturity (**Figure 2**). The dry matter accumulation pattern of rice showed a slow exponential growth, period of linear growth and a period of constant weight. Considering the nitrogen fertilization, the highest dry matter (1138.40 $g \cdot m^{-2}$) was obtained when rice plants were fertilized with 100 kg N ha^{-1} and the lowest

Table 1. Effect of nitrogen levels on number of tillers per hill of new rice variety over the growing period.

Nitrogen levels ($kg \cdot ha^{-1}$)	Days after transplanting						
	15	25	35	45	55	65	75
0	1.44b	4.36c	10.89b	11.44b	10.11c	10.33bc	8.56c
20	1.78ab	4.82b	12.33b	12.56ab	10.24c	8.33c	8.67c
40	1.89ab	5.30b	12.67ab	12.89ab	11.14b	11.00b	9.11bc
60	2.00a	5.84ab	13.11ab	13.22ab	11.44b	10.56b	9.56b
80	2.11a	6.41ab	13.67a	14.00a	12.00ab	10.44bc	10.33b
100	2.11a	6.78a	14.11a	14.44a	12.78a	12.67a	11.44a
LSD (0.05)	0.5536	0.573	3.8571	2.9764	1.8399	2.9853	1.9898
CV (%)	16.11	5.64	16.57	12.5	8.96	15.55	11.38

Values followed by different letters in column indicate significant differences by LSD test.

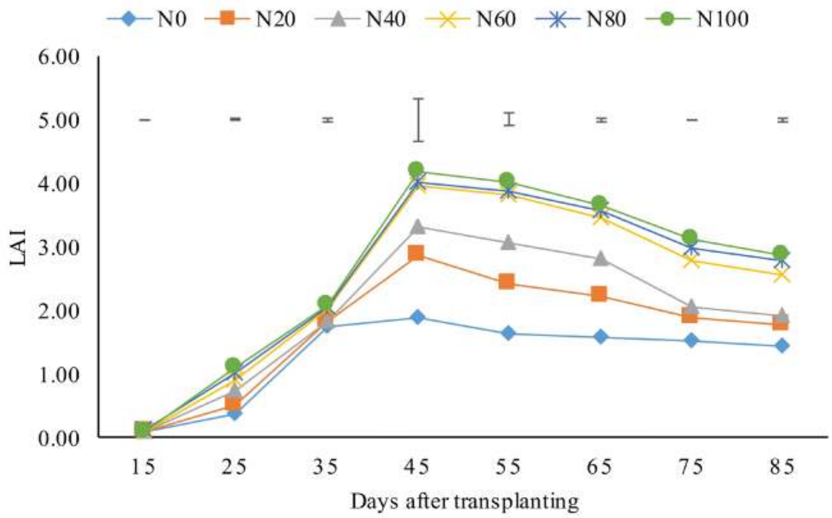

Figure 1. Changes in leaf area index (LAI) of new rice variety due to nitrogen levels over the crop growth.

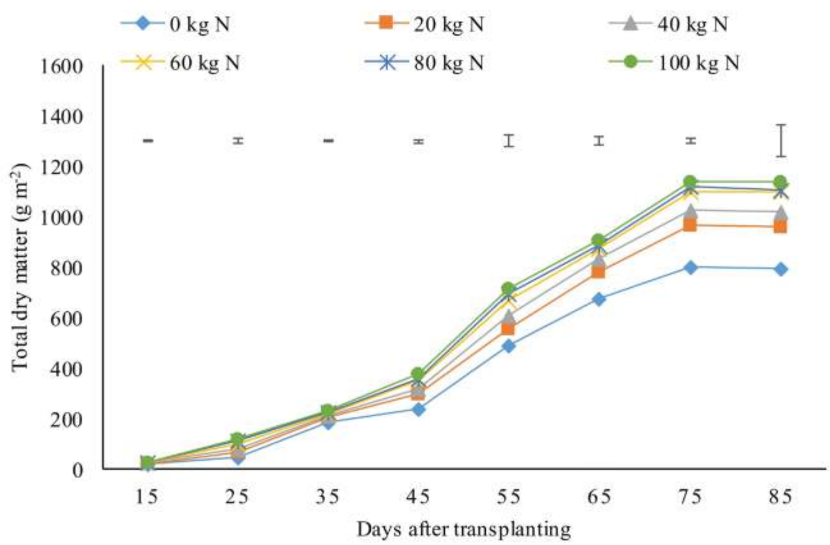

Figure 2. Dry matter accumulation in rice as influenced by nitrogen levels over the crop growth stages.

(19.74 g·m^{-2}) dry matter was obtained in control treatment. Applied nitrogen increased dry matter production of the variety (**Figure 2**). Elevated nitrogen supply can boost dry matter content through production of photo-assimilates via leaves which is the center of plant growth during vegetative stage and later distribution of assimilates to the reproductive organs [20] [21]. Furthermore, dry matter production in rice is significantly related to intercept photosynthetically active radiation [22]. Low N concentrations in plant leaves have been described as a limiting factor for reducing radiation use efficiency and biomass productivity [23] resulting lower dry matter production of rice. To develop crop growth models, information on dry matter production and partitioning between diverse plant parts is crucially needed [24] which conspicuously influenced by nitrogen fertilizer application. Dry matter partitioning to the reproductive organs hinge on number, capacity and activity of physiological sinks [15].

Pattern of dry matter partitioning into leaf, stem, leaf sheath and panicle of rice was almost similar across the treatment levels (**Figure 3**). Dry matter partitioning into leaf, stem and leaf sheath increased up to 65 DAT while panicle dry weight continued to increase till 75 DAT. Dry matter partitioning into vegetative parts decreased after

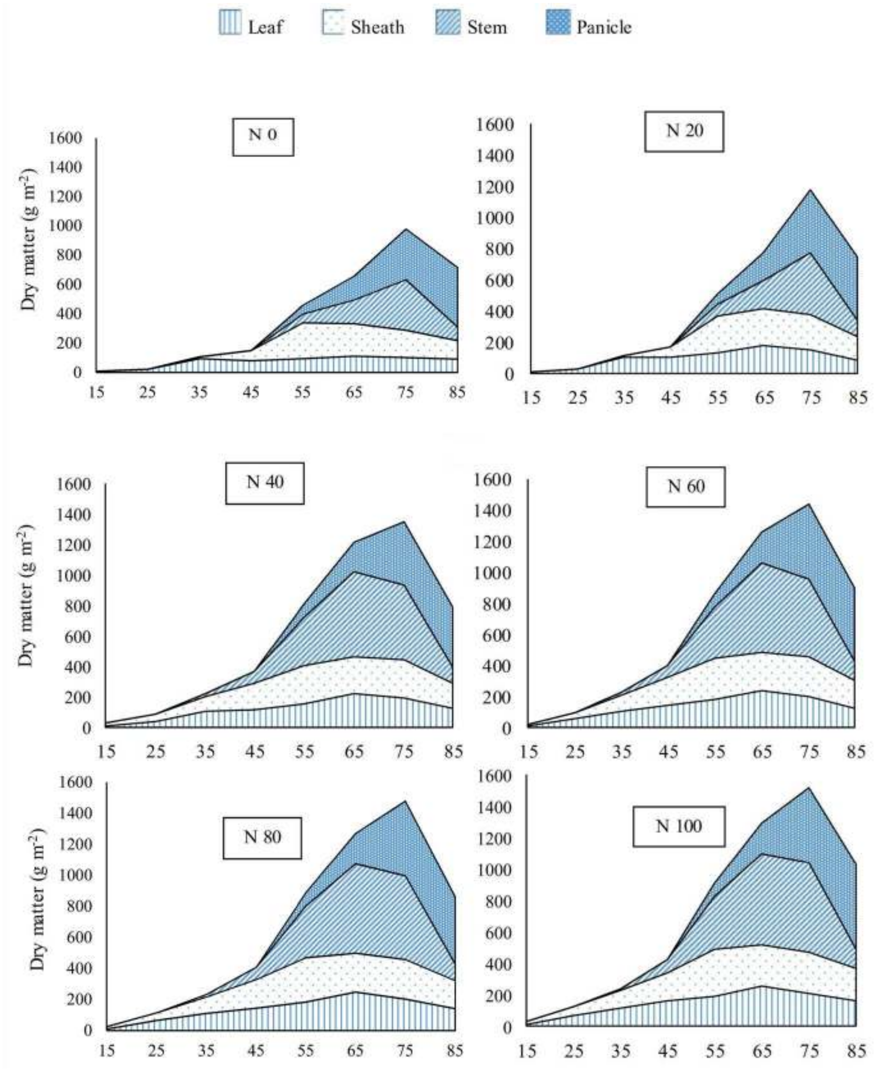

Figure 3. Pattern of dry matter partitioning to different parts of rice as influenced by time course and nitrogen levels.

65 days after transplanting which indicated remobilization of assimilates from vegetative parts towards developing grain. Application of nitrogen caused significant difference in the pattern of partitioning of dry matter of rice at all the growth stages where low nitrogen fertilizer levels triggers allocation of lowest dry matter to all plant parts.

The trend of crop growth rate under different doses of nitrogen fertilizer illustrated that, crop growth rate of the variety was slow at early growth stage which became peaked at flowering stage and again declined towards maturity stage and showed even negative values (**Figure 4**). Nevertheless, the lowest crop growth rate (−25.96 g m^{-2}·day^{-1}) was recorded at 85 days after transplanting when crop was fertilized with 100 kg N ha^{-1}. Contrary, the highest crop growth rate (33.99 g·m^{-2}·day^{-1}) was obtained when the crop was fertilized with 100 kg N ha^{-1} at 45 days after transplanting. Crop growth rate was slower at the earlier stage of the variety. Slow crop growth rate at earlier stages of the rice variety might be due to lower leaf development which act as a main organ of photosynthesis on which growth rate depends [25]. The phenomena of crop growth rate tend to be low again during later stage and negative towards maturity considerably due to several reasons. These are 1) excessive leaf senescence after reproductive stage diminishing photosynthesis rate [21] [23], 2) upkeep of respiration burden increases over time which hinge on biomass and particularly its N content [26], 3) ineptitude of the plants to maintain post floral N uptake [27] [28] or cannot store significant N reserves in other organs excepting leaves

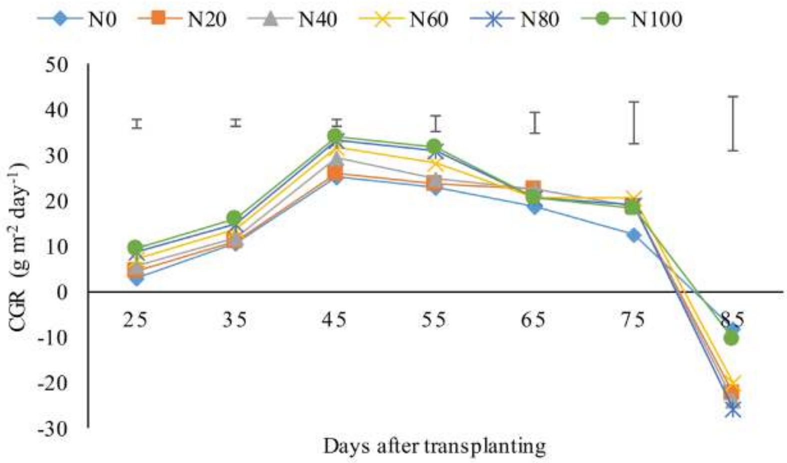

Figure 4. Crop growth rate of rice as influenced by nitrogen level over the growing periods.

[29]. In this context, application of higher rates of nitrogen can minimize curtail leaf area loss and endure high canopy photosynthetic rates to maintain better crop growth.

Results presented in the **Figure 5** showed that net assimilation rate (NAR) of rice variety maintained a declining trend after 25 DAT irrespective of time counts and nitrogen rates. However, the declining trend of NAR was observed steady from 45 to 65 DAT of the variety. Afterwards NAR values of the variety followed the negative trend. The descending even negative trend of NAR might be due to, less productivity of the leaves at the later stage of crop growth [21]. Furthermore, applied nitrogen levels hasten leaf production resulting leaves shading owing to early closure of canopy which hinder solar radiation absorbed by the leaves therefore less photosynthetic assimilates produced which causes lowering the net assimilation rate. Similar results about the pattern of the changes of NAR curve were reported by Esfahani *et al.* [30], Singh *et al.* [31] and Yang *et al.* [32].

3.2. Yield Components and Yield

Nitrogen levels had significant effect on the number of panicles per hill of rice (**Table 2**). The number of panicle per hill increased with increased level of nitrogen. The highest number of panicle per hill (8.8) was obtained when 60 kg N ha^{-1} was applied and the lowest (7.07) from control treatment. The number of effective tillers rather than total number of tillers contributes more to enhance productivity of rice plant. Nevertheless, the number of productive tillers depends on environmental conditions especially nutrient during tiller bud initiation and subsequent developmental stages [33] [34]. The lower of tiller number in present study was attributed to the failure in competition for nitrogen at lower level and aggravate death of the tillers due to mutual shading [35]. Another explanation is that, competition for assimilates exists between developing panicles and young tillers during the beginning of panicle development causing suppression of growth of many young tillers therefore they may senesce without producing panicle [36] [37]. Similar results were also reported by other authors [38] [39].

Number of filled grains per panicle varied significantly due to variable nitrogen rates. The highest number (100.11) of filled grains per panicle was recorded at 60 kg N ha^{-1}. While, the lowest number of filled grains (72.92) per panicle of rice was found at control treatment. On the contrary, number of unfilled grains per panicle was reversal to that of filled grains at variable nitrogen levels. Thus number of unfilled grains per panicle was the highest (23.48) at control and the lowest (17.80) at 60 kg N ha^{-1}. The variability in number of filled or unfilled grains per panicle is dependent on many factors such as genotypes, cultural techniques and growing environment of the crop [40]. Excessive as well as low application of nitrogen fertilizer causes lower number of filled grains and higher number of unfilled grains per panicle of rice (**Table 2**). Optimum amount of nitrogen fertilizer on the other hand produces maximum number of filled grains and minimum number of unfilled grains per panicle. These findings were in agreement with the findings of Lawal and Lawal [41] who reported that adequate supply of nitrogen is essential for grain development of rice and to increase filled grains per panicle. Higher number of grains per panicle at higher nitrogen rate might be due to higher nitrogen absorption which

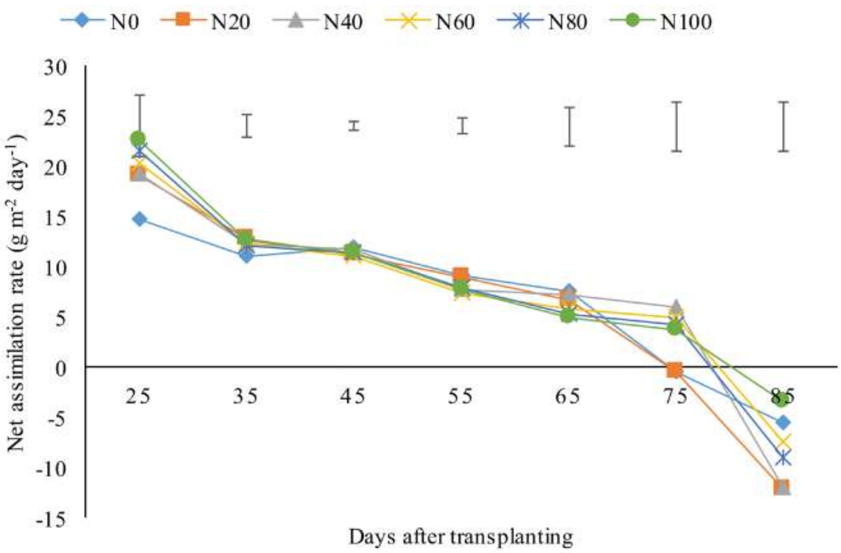

Figure 5. Net assimilation rate of rice as influenced by nitrogen level over the growing periods.

Table 2. Yield components and yield of rice as affected by nitrogen rates.

Nitrogen rates (kg·ha^{-1})	Panicle per hill	Filled grains per panicle (No.)	Unfilled grains per panicle (No.)	Total grains per panicle (No.)	1000 grain weight (g m)	Grain yield (t·ha^{-1})
0	7.07b	72.92d	19.80a	92.72e	25.83b	3.29f
20	8.60ab	78.86c	18.55b	97.41d	25.70b	3.79e
40	7.93ab	87.85bc	18.48b	106.33c	25.90b	4.39d
60	8.80a	100.11a	18.20c	118.31a	27.33a	5.36a
80	8.20ab	95.83b	20.35bc	116.18b	27.43a	5.00b
100	8.27ab	93.64b	23.48b	117.12ab	27.37a	4.81c
LSD (0.05)	1.37	10.78	1.38	7.87	0.66	1.35
CV (%)	9.29	6.56	3.75	5.46	0.6441	0.1049

Values followed by different letters in column indicate significant differences by LSD test.

favored formation of higher number of branches per panicle [42].

Total grains per panicle also varied significantly due to different levels of applied nitrogen. Grains per panicle increased with the increase of nitrogen levels and the highest grains (118.31) per panicle were formed when the crop received 60 kg N ha^{-1}. The lowest grains (92.72) per panicle were observed at 0 kg N ha^{-1}. Application of nitrogen fertilizer improved grain number of rice. Higher number of grains per panicle at higher nitrogen rate might be due to higher nitrogen absorption which favored formation of higher number of branches per panicle [42].

The maximum thousand grain weights (27.43 g) was observed at 80 kg N ha^{-1} which was statistically similar with 60 and 100 kg N ha^{-1}. The lowest thousand grain weight (25.70 g) was produced with 20 kg N ha^{-1} which was similar to that of 0 and 40 kg N ha^{-1}. In case of thousand grain weight, the variation is very low among the treatments as it known to be by the genetically controlled character. Similar results were found by other scientists [43] [44] with nitrogen fertilizer management and concluded that there is little opportunity to improve grain size through agronomic management.

The highest grain yield (5.36 t·ha^{-1}) was found when the crop was fertilized with 60 kg N ha^{-1} followed by 80 kg N ha^{-1} (4.99 t·ha^{-1}) and the lowest yield (3.29 t·ha^{-1}) was recorded from control (**Table 2**). The decrease of grain yield after 80 kg N ha^{-1} indicated that the variety is efficient in nitrogen use at 60 kg N ha^{-1} that causes corresponding increase in growth and yield components. Application of 60 kg N ha^{-1} increased panicle per hill, grains per panicle, filled grains per panicle and seed size which ultimately increased the yield of the rice variety. Grain yield of rice plant is highly relying on the number of spike-bearing tillers produced by each plant, filled grains and grains weight [45]. The increment of grain yield in this study at higher nitrogen levels might be due efficient absorption of nitrogen and other elements which raise the production and translocation of the dry matter from source to sink [46] [47].

3.3. Dry Matter Translocation and Nitrogen Use Efficiency

Applied nitrogen had significant effect on apparent dry matter translocation of rice. Dry matter translocation from vegetative to reproductive organ increased with increased nitrogen levels upto 60 kg N ha^{-1} and then decreased (**Table 3**). For reaching maximum rice yield, the best photosynthesis activity of flag leaf is needed as 60% - 90% of total carbon in panicle is derived from photosynthesis after heading [48]. Rest of photoassimilates needed for grain is remobilized from vegetative organs [49]. The amount of dry matter remobilization in rice, however, is affected by genotypes, cultural practices and growing environments [50]. This result is in consistent with the result of Lin *et al.* [51] who reported that different rate of remobilization is related to agronomic practices especially applied nitrogen.

In present study, the highest amount of remobilization (232.93 $g \cdot m^{-2}$) was recorded from 60 kg N ha^{-1} treatment and the lowest (130.93 $g \cdot m^{-2}$) from control treatment. Nitrogen use efficiency of the rice variety increased with elevated levels of applied nitrogen upto 60 kg N ha^{-1} and thereafter declined (**Table 3**). Thus the lowest nitrogen use efficiency (115.34 kg grain/kg N applied) was noted at 100 kg N ha^{-1} and the highest (344.50 kg grain/kg N applied) at 60 kg N ha^{-1}. The estimation of nitrogen use efficiency (NUE) in crop plants is crucially needed to assess the fate of applied nitrogen and their role in improving maximum economic yield through efficient absorbed or utilization by the plant. The diminishing trend of NUE at higher N rates pointed out that rice plants are unable to absorb or utilize N at higher rates or the rate of N uptake by plant cannot keep pace with the loss of N [16]. Nitrogen usually loss by means of ammonia volatilization, denitrification, surface runoff and leaching in the soil floodwater system [52] [53] causing enormous problems for instance environmental pollution, increased production cost, grain yield reduction and could even lead to global warming [54] [55]. Nonetheless, the magnitude and nature of N losses vary depending on the timing, rate, and method of N application, source of N fertilizer, soil chemical and physical properties, climatic conditions and crop status [56]. Decreases in N uptake efficiency at higher N rates have also been reported by Eagle *et al.* [57], Timsina *et al.* [58] and Mae *et al.* [59].

4. Conclusion

From the results it may be concluded that growth, yield and nitrogen use efficiency of the new rice variety were significantly influenced by different levels of nitrogen fertilizer. Although growth of the variety increased with increased nitrogen levels, assimilate mobilization towards grain was higher at 60 kg N ha^{-1}. Consecutively, the

Table 3. Dry matter translocation and nitrogen use efficiency of rice at variable nitrogen rates.

Nitrogen levels ($kg \cdot ha^{-1}$)	Apparent dry matter translocation ($g \cdot m^{-2}$)	Nitrogen use efficiency (kg/kg N applied)
0	130.93cd	-
20	152.10c	250.42b
40	199.30b	272.92b
60	232.93a	344.50a
80	109.21e	212.86c
100	141.77c	151.34d
LSD (0.05)	14.854	28.466
CV (%)	1.94	6.14

Values followed by different letters in column indicate significant differences by LSD test.

variety produced the highest yield with 60 kg N ha^{-1} with the highest nitrogen use efficiency. Further research may include characterization and photosynthetic capacity of flag leaf so that inherent physiology may be exploited for further yield improvement of the new variety.

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