Low-level Substitution of Urea Fertilizer with Organic Manure Increased Grain Yield, Harvest Index, and Nitrogen Use Efficiency of Wheat Under Subtropical Conditions in Bangladesh

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ABSTRACT

Inorganic-organic integrated soil fertility management is often suggested to improve soil health, reduce environmental risks, and strengthen the resilience of agroecosystems. However, limited research has focused on the effect of inorganic-to-organic nitrogen (N) fertilizer substitution on the growth, yield and nitrogen use efficiency (NUE) of wheat under the subtropical monsoon climatic conditions of this region. Therefore, seven quintuplicated treatments were established in a wheat-growing pot culture system during the winter season of 2023-2024 following completely randomized design (CRD) at the research field of Sher-e-Bangla Agricultural University, Dhaka, with varying levels of N-equivalent substitution between chemical fertilizer (urea) and organic manure (OM). The treatments were N_0=zero N fertilizer (control); N_1=120 kg N ha^{-1} from urea; N_2=100 kg N ha^{-1} from urea + 20 kg N ha^{-1} from OM; N_3=80 kg N ha^{-1} from urea + 40 kg N ha^{-1} from OM; N_4=60 kg N ha^{-1} from urea + 60 kg N ha^{-1} from OM; N_5=40 kg N ha^{-1} from urea + 80 kg N ha^{-1} from OM; and N_6=120 kg N ha^{-1} from OM. Despite sources, N fertilization significantly improved plant height, leaf area index (LAI), effective tillering, yield-contributing attributes and yield of wheat. The tallest plant (89.33 cm) was observed from the N_1 treatment, which was 19.6% greater than the control treatment. The plants with N_1 treatment also produced 54.4% greater LAI at heading. Total chlorophyll content of the flag leaf was highest under N_1 treatment, and differences among N_2, N_3, and N_4 treatments were non-significant. The N_1, N_2, N_3, N_4, N_5, and N_6 treatments increased total dry matter accumulation in plants by 111.67%, 97.2%, 93.9%, 84.4%, 73.3%, and 69.4%, respectively. The maximum effective tiller (1.60 $plant^{-1}$) and thousand grain weight (45.7 g) were observed under N_1 treatment, which was 14.3% and 43.9% greater than the control but statistically identical with N_2 and N_3 treatments. The highest grain yield (345.56 g m^{-2}) and highest harvest index (45%) of wheat were recorded under the N_1 treatment, which was statistically similar to the N_2 treatment. The highest NUE of wheat (28.8 g g^{-1}) was recorded with the N_1 treatment, which was statistically identical with the N_2 treatment. Current results suggest that up to 33% of N-equivalent urea fertilizer substitution with organic manure could serve as a suitable eco-friendly alternative to sole reliance on chemical fertilization for wheat farming in this region.

Keywords: *Wheat; Organic manure; Nitrogen fertilizer; Grain yield; Nitrogen Use Efficiency.*

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is an important cereal crop that contributes to global food and nutritional security. Globally wheat cultivation area covering about 200 million hectares with annual grain production nearly 805 million tons (FAO, 2025). Along with rice and maize, wheat plays an important share of human caloric intake. It provides about 20% of global dietary calories and protein (Shiferaw et al., 2013), making it an essential ingredient in food products. Besides, wheat has a substantial impact on global agricultural trade, food prices, and economic stability (Fischer et al., 2014). In Bangladesh, wheat is the second most important cereal after rice (Hossain et al., 2019). Its consumption has steadily increased due to dietary diversification and the rising popularity of bread, noodles, and processed foods (Rahman and Zhang, 2018).

Wheat growth and yield is highly responsive to nitrogen (N), a primary nutrient that promotes vegetative growth, leaf expansion, tillering, chlorophyll synthesis, and biomass accumulation (Roman et al., 2018). Traditionally, farmers in Bangladesh rely heavily on chemical N fertilizers, particularly urea, to achieve higher yields (Hossain et al., 2019). Although beneficial in the short-term, continuously overusing chemical fertilizers causes nutritional imbalances and reduces soil fertility (Sadaf et al. 2017; Hossain et al. 2021; Ladha et al. 2005). Furthermore, high doses of chemical N fertilizers often lead to low nitrogen use efficiency (NUE) in wheat farming systems (Rahman and Zhang, 2018). Such unsustainable chemical fertilization resulting in substantial N losses through leaching, volatilization, and denitrification, creating both economic and environmental issues (Rahman and Zhang, 2018; Ladha et al., 2005). Conversely, partial substitution of chemical N fertilizers with organic manures has suggested as a sustainable approach to maintaining wheat productivity and soil health (Du et al. 2020; Lal, R. 2006).

Organic manures such as composted cattle manure supply not only N but also phosphorus, potassium, and micronutrients, thereby enhancing soil fertility and structure (Zhao et al., 2024). Their slow mineralization enhances nitrogen use efficiency (NUE) and reduces N losses by synchronizing nutrient supply with crop demand. Moreover, manures increase soil organic matter, improve water-holding capacity, and stimulate beneficial microbial activity, which is critical for sustaining productivity of intensive cultivation system as follows in Bangladesh (Sadaf et al., 2017).

Recent studies have shown that integrated use of organic manure and chemical N fertilizer increases wheat growth and yield compared to sole chemical fertilizer use. For instance, Islam et al. (2011) reported that substituting 25-50% of urea N with manure enhanced plant height, tillering, leaf area index, and grain yield. Similarly, Hossain et al. (2019) demonstrated that combined organic-inorganic N fertilization improved biomass accumulation, delayed leaf senescence, and increased harvest index. These findings suggest that partial substitution could sustain or even increase yields while improving soil health. Therefore, selection of proper dose of organic manure for partial substitution chemical fertilizer is critical for economic yield return and sustainable soil fertility management. However, most fertilizer substitution studies are conducted under arid temperate condition of central Asia. Only few studies were conducted under subtropical monsoon climatic conditions of Bangladesh. Therefore, this study combined

التعليق [M1]: Shiferaw etal.,2013; Alaamer et al.,2022.

Alaamer S.A, S.K.Alsharifi, N. Shtewy . 2022. Wheat parameters under influence of the depths and cultivation machinery. IOP Conf. Ser. Earth Environ. Sci. 1060(1):012131.http://doi:10.1088/17 55 1315/1060/1/012131.2022.

التعليق [M2]: Amer et al.,2025

Amer. K.Z, Azawi.A, Jabur.H.A, Al-Shammay.A.A.G and Alsharifi.S. 2025. The impact and analysis of mechanical factors of the mechanized unit on the production of "Vigna radiata L." crop.Natural and Engineering Sciences.10 (1): 418-424. doi:10.28978/nesciences.1651195

التعليق [M3]: Delete

التعليق [M4]: ?

التعليق [M5]: The introduction may be supported with more recent literatures seven different combinations of N-equivalent chemical (urea) fertilizer to organic manure substitution treatments to evaluate their impact on wheat growth yield and nitrogen use efficiency under this subtropical monsoon climatic condition of Bangladesh.

2. MATERIAL AND METHODS

2.1. Experimental Site

The pot-culture experiment was carried out at the research farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh, during the Rabi season from mid-November 2023 to mid-March 2024). This site is situated at 23°74′N latitude and 90°35′E longitude, with an altitude of 8.1 meters above sea level. The area falls within the subtropical monsoon climatic zone and belongs to the Modhupur Tract (AEZ-28).

2.2 Planting Material

BARI Gom 31 was used for this study. The seed of the selected cultivar was collected from the Bangladesh Wheat and Maize Research Institute (BWMRI), Dinajpur. The variety is characterized by its short height (91-98 cm) and strong and lodging-resistant stem. It matures in 100-108 days. Each ear typically contains 47-52 grains, which are white and glossy, with a weight of 48 to 52 grams per thousand grains. The variety exhibits resistance to leaf and stem rust diseases, specifically the Ug99 race, and demonstrates good tolerance to leaf spot disease.

2.3 Experimental Design and Treatments

The pot culture experiment was conducted under field conditions following complete randomized design (CRD) with five replications. To achieve intended objectives, seven N equivalent inorganic-organic fertilizer substitution treatments were established. Urea ($CO(NH_2)_2$) with 46% N was used for a chemical fertilization whereas decomposed cow dung was used as organic manure (OM). The treatments were: The treatments were N_0=zero N fertilizer (control); N_1 = 120 kg N ha^{-1} from urea; N_2=100 kg N ha^{-1} from urea + 20 kg N ha^{-1} from OM; N_3=80 kg N ha^{-1} from urea + 40 kg N ha^{-1} from OM; N_4=60 kg N ha^{-1} from urea + 60 kg N ha^{-1} from OM; N_5=40 kg N ha^{-1} from urea + 80 kg N ha^{-1} from OM; and N_6=120 kg N ha^{-1} from OM.

2.3 Pot preparation, treatment application and cultural managements

In this pot culture experiment, a total 35 plastic pots were used to establish and maintain a healthy wheat crop stand. Each unit pot was 30 cm top surface diameter and 29 cm in height, maintaining a 10 kg soil. The pots were arranged in rows with 30 cm spacing. Sandy loam alluvial soil was used for pot preparation as it provides good drainage and aeration while retaining nutrient and water. Fertilizer treatments were applied to each pot on surface area basis. Before application of organic manure retreatments, the total N content in organic manure was estimated following Kjeldahl method (reference). All Organic manure treatments were applied as basal fertilizer during final pot preparation. Among total urea fertilizer, 60% will be applied before sowing as a basal dose and the rest 40% will be top-dressed in two be equal splits at early tillering and before heading stages. Besides, 30 kg P ha^{-1}, and 60 kg K ha^{-1} from chemical sources will also be applied to wheat across all treatments following recommendation (BARC, 2018). Wheat seed was sown in November 15, 2023 at seed rate 35 kg ha^{-1}. Irrigation was applied gravimetrically and each pot was rewetted to maintain a 70 to 90 % field capacity throughout the growing season. Other intercultural operations (weeding and pest management) were also performed whenever necessary to ensure the normal growth of the crops.

2.4 Sampling and data collection

2.4.1 Plant height and Leaf area index (LAI)

Plant height data were obtained by measuring the height from ground level to the top of the spikes of five selected plants during the final harvest of wheat. The leaf area (LA) was measured at heading by randomly collecting six leaves from the lower, middle, and upper portions of the plant. The collected leaves were scanned using a flatbed scanner (Canon CanoScan LiDE 400) to get leaf areas, and mean values were calculated. The mean leaf area was multiplied by the total number of fresh leaves from all the plants in each unit pot to determine the total leaf area for each pot. Finally, the LAI was calculated as the ratio of total leaf area to the ground surface area.

2.2 **Dry matter accumulation**

Data pertaining to dry matter accumulation and leaf area (flag leaves and top three leaves) were collected through destructive sampling method. At the harvest, five plants from each pot were sampled. Sample plants were separated root, leaf, stem (culm + leaf sheath), spike and total. After air drying, the segmented plant samples were kept in separated envelopes and oven dried at 70 °C for 72 hours. Dry weight of each component was determined with an electric balance, and mean values were calculated. Finally total dry matter (TDM) was calculated from dry weight of different plant parts.

2.3 Estimation of leaf chlorophyll

Chlorophyll content in flag leaf was determined at heading stages. Leaf chlorophyll was extracting with 80% acetone, and absorbance was measured using double beam spectrophotometer. Chlorophyll content in flag leaf was calculated according to Witham *et al.* (1986).

2.4 Yield components

For yield studies, all plants with effective tiller of each pot were selected at maturity. The tiller having at least one grain spike^{-1} was considered as effective one. Five spikes from each hill (of each pot) were threshed. Grain and sterile spikelets were separated. After separation, the grains and sterile spikelets were counted by an automatic counter and then grain spike^{-1}, sterile spikelets spike^{-1}, total spikelets spike^{-1} and spikelets sterility (%) were calculated.

2.5 Yield

Grain yield: Grain yield obtained from each pot was recorded, and grain yield was estimated and adjusted to 14% moisture content.

Straw yield: The weight of straw of harvested area per pot was recorded after drying.

Biological yield: The sum of grain yield and straw yield was regarded as biological yield.

$$Biological\ yield\ (BY) = Grain\ yield + Straw\ yield$$

2.6 Harvest Index

Harvest index (HI) is the ratio of grain yield (economic yield) to biological yield and expressed in percent (%). It was calculated using the following formula.

$$Harvest\ index\ (\%) = \frac{Grain\ yield}{Biological\ yield} \times 100 \quad \text{.................. (4)}$$

2.7 Nitrogen Utilization Efficiency (NUE)

Nitrogen utilization efficiency (NUE), also called nitrogen use efficiency of wheat was was calculated using the equation 5.

التعليق [M6]: Source

$$Nitrogen\ utilization\ efficiency\ (NUE) = \frac{Grain\ yield}{Nitrogen\ application\ rate} \quad \text{............ (5)}$$

2.8 Data analysis

The collected data were subjected to analysis of variance (ANOVA) technique and the means were adjudged by the least significance difference (LSD). Correlation and regression analysis, and graphical presentation were carried out using Microsoft Excel software.

3. RESULTS AND DISCUSSION

3.1 Plant height

Plant height of wheat showed significant variation at final harvest under different levels of chemical to organic fertilizer substitution treatments (Table 2). The maximum plant height (89.33 cm) was produced under the N1 treatment, which was 19.6% greater than control but statistically similar with N3 and N4 treatments. The N0 (control) treatment produced the shortest plant (74.67cm). Compared to N0 treatment, plant height of wheat under N2, N3, N4, N5, and N6 treatments was improved by 14.7%, 15.8%, 16.2%, 10.9%, and 11.6%, respectively.

The results of this study are consistent with previous studies. Applying mineral fertilizers alone or in combination with organic fertilizers Idris and Wisal (2001) observed enhancement in plant height. Woyema et al. (2012) reported the greatest wheat plant height when chemical was applied together with organic fertilizers. Hossain et al. (2002) also noted that wheat reached its maximum height (65.5 cm) at an application rate of 92 kg N ha^{-1}. Although our result found a gradual declining trend in plant height with increase in organic manure increments, overall data indicated that N fertilization improved soil nitrogen availability and chemical fertilizer have an edge on plant available N supply which likely improve plant growth. This effect can be attributed to the pivotal role of nitrogen in promoting cell division, expansion, and enlargement, thereby stimulating vegetative growth in wheat plants.

3.2 Leaf area index

The leaf area index (LAI) of wheat found significant improvements with selected fertilizer substitution treatments at heading stage (Figure 1). The highest leaf area index (4.51) was obtained from N_1 (120 Kg N ha^{-1} from Urea) which was 54.4% greater over the control treatment. The lowest LAI (2.92) was obtained from the control treatment. The N_2, N_3, N_4, N_5, and N_6 treatments increased the LAI by 48.3%, 41.1%, 33.2%, 28.8%, and 29.8%, respectively. Applying nitrogen fertilizer during the early growth stages of wheat increases leaf area by slowing leaf senescence, maintaining photosynthetic activity, and prolonging the duration of leaf area, which ultimately produced a higher LAI than the control (Frederick and Camberato, 1995). The application of organic manure increased availability of plant nutrients, enhanced soil water retention, and minimized nitrogen loss through NH_3 volatilization; these effects may have contributed to the increase in LAI observed in our study.

3.3 Chlorophyll content of flag leaf

Chlorophyll content of flag leaf was significantly influenced by selected N fertilization treatments (Table 1). The highest chlorophyll-a content of flag leaf was observed (1.76 mg g^{-1}) from N_1 treatment which was significantly improved over the N0 (control) control treatment but statistically similar to N_2, N_3, and N_4 treatments. The N_0 treatment had lowest chlorophyll-a content (1.19 mg g^{-1}). Compared to the control, the N_1, N_2, N_3, N_4, N_5, and N_6 treatments increased chlorophyll-a content of flag leaf by 47.9%, 46.5% 45.9%, 44.3%, 38.9%, and 37.6%, respectively. The N1 treatment also maximized chlorophyll b content (1.073 mg g^{-1}) in the flag leaf which was followed N_2 treatment which contained 0.953 mg g^{-1} fresh leaf. Conversely, the lowest chlorophyll b content (0.670 mg g^{-1}) was observed under N_0 treatment. However, compared to the control treatment the chlorophyll b content was improved by 60.1%, 42.2%, 40.7%, 35.4%, 32.8% and 34.7% under the N_1, N_2, N_3, N_4, N_5, and N_6 treatments, respectively.

Data table 1 indicated that total chlorophyll of flag leaf significantly increased with N fertilization. The highest total chlorophyll content (2.834 mg g^{-1}) was observed in N_1 treatment while the lowest total chlorophyll content of leaf (1.856 mg g^{-1}) was found in N_0 treatment. Relative to control treatment N_1, N_2, N_3, N_4, N_5, and N_6 treatments improved total chlorophyll by 52.7%, 45.2%, 44.3%, 41.3%,37.2% and 36.7%, respectively.

Nitrogen is a key structural component of both chlorophyll and proteins; thus, it plays an essential role in chloroplast formation and chlorophyll accumulation (Daughtry et al. 2000). Therefore, we found significant improvements in flag leaf chlorophyll contents with nitrogen fertilization from chemical or chemical-organic combined sources. Previous studies also found significant improvements in leaf chlorophyll content with N inputs in wheat farming (Azab et al., 2016, Mohammadi et al. 2017, and Saharan et al. 2018). However, the higher chlorophyll content (chlorophyll a, b, and total) observed under N1 treatment (120 kg N ha^{-1} from urea) likely attributed to rapid release of nitrogen in soil solution from chemical fertilizer which is readily available to plants. Besides high mobility of N in plant system may also contributed to higher chlorophyll formation under N fertilization across the wheat developmental stages.

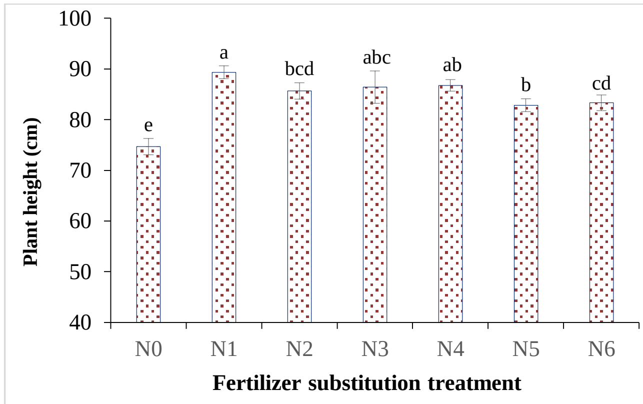

Figure 1. Effect of chemical to organic fertilizer substitution on plant height of wheat at harvest. Different letter in a bar indicates significant variation existed among treatments. Error bar in a bar indicates standard deviation of mean. Here, N_0=Zero N fertilizer (Control); N_1 =120 kg N ha^{-1} from Urea; N_2= 100 kg N ha^{-1} from Urea + 20 kg N ha^{-1} from organic manure; N_3= 80 kg N ha^{-1} from Urea + 40 kg N ha^{-1} from organic manure; N_4= 60 kg N ha^{-1} from Urea + 60 kg N ha^{-1} from organic manure; N_5= 40 kg N ha^{-1} from Urea + 80 kg N ha^{-1} from organic manure; and N_6= 120 kg N ha^{-1} from organic manure.

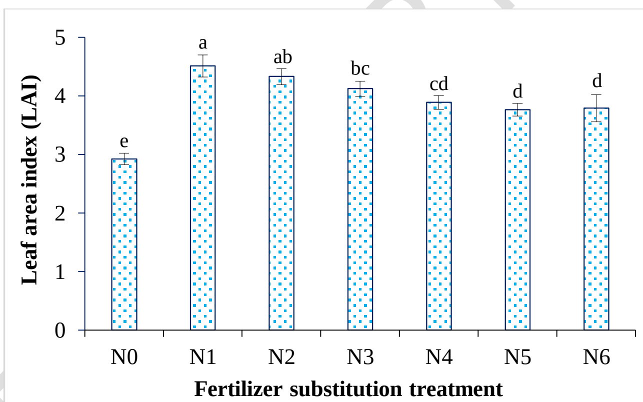

Figure 2. Effect of chemical to organic fertilizer substitution on leaf area index (LAI) of wheat at heading. Different letter in a bar indicates significant variation existed among treatments. Error bar in a bar indicates standard deviation of mean. Here, N_0 = Zero N fertilizer (Control); N_1 = 20 kg N ha^{-1} from Urea; N_2= 100 kg N ha^{-1} from Urea + 20 kg N ha^{-1} from organic manure; N_3= 80 kg N ha^{-1} from Urea + 40 kg N ha^{-1} from organic manure; N_4= 60 kg N ha^{-1} from Urea + 60 kg N ha^{-1} from organic manure; N_5= 40 kg N ha^{-1} from Urea + 80 kg N ha^{-1} from organic manure; and N_6 = 120 Kg N ha^{-1} from organic manure.

3.4 Effective tiller per plant

Fertilizer substitution treatments showed significant variation in the number of effective tillers per plant of wheat as outlined in the Figure 2. Result revealed that highest no. of effective tiller per plant (1.60) was recorded from N_1 treatment which was 14.3% greater than control, but which was found to be statistically at par to treatment N_2 and N_3 while the treatment N_0 recorded lowest number of effective

Table 1. Effect of inorganic-organic integrated N management on plant height, leaf area index (LAI), and Chlorophyll content of flag leaf of wheat.

Treatment	**Chlorophyll content of flag leaf (mg g^{-1} fresh weight)**		
	Chlorophyll a	**Chlorophyll** b	**Chlorophyll (a+b)**
N_0	1.190 d	0.670 c	1.856 d
N_1	1.760 a	1.073 a	2.834 a
N_2	1.743 a	0.953 ab	2.694 b
N_3	1.737 a	0.943 b	2.679 b
N_4	1.717 ab	0.907 b	2.622 bc
N_5	1.653 bc	0.890 b	2.546 c
N_6	1. 637 c	0.903 b	2.538 c
LSD	0.0634	0.1279	0.1216
CV	2.21	8.07	2.74

Different letter in a column indicates significant variation existed among treatments. Here, N_0 = Zero N fertilizer (Control); N_1 = 120 kg N ha^{-1} from Urea; N_2= 100 kg N ha^{-1} from Urea + 20 kg N ha^{-1} from organic manure; N_3= 80 kg N ha^{-1} from Urea + 40 kg N ha^{-1} from organic manure; N_4= 60 kg N ha^{-1} from Urea + 60 kg N ha^{-1} from organic manure; N_5= 40 kg N ha^{-1} from Urea + 80 kg N ha^{-1} from organic manure; and N_6 = 120 kg N ha^{-1} from organic manure.

tillers per plant of 1.42. However, the N_2, N_3, N_4, N_5, N_6 treatments which were 11.4%, 6.4%,5%, 2.9%, and 1.43% greater than control. Previous studies indicated higher tiller formation in wheat due to nitrogen fertilization (Sheoran, et al. 2017). For instance, Tilahun Abera (2017) reported 1.97 tiller per plant at 92 kg N ha^{-1} which was significantly improved over control. In general, inorganic N sources like urea, nitrate etc. can drive rapid tiller formation because of available N supply to the crop. Nitrogen availability influences hormonal signals (cytokinins vs gibberellins) in tiller-nodes and in turn tiller formation (Bauer B, and von Wirén N. 2020). Organic sources alone often result in lower number of effective tiller formation unless supplemented by inorganic N (Sheoran, et al. 2017), likely due to insufficient nutrient supply from slow mineralization of organic manure.

3.4 Dry matter accumulation in plant parts

Nitrogen fertilization had significant effect ($P < 0.05$) on root dry matter accumulation of wheat at final harvest (Table 2). The maximum accumulation of root dry matter (1.42 g plant^{-1}) was recorded with N_1 treatment which was 144.8% greater over the N_0 (control) treatment and significantly improved over other treatments. The lowest root dry matter accumulation (0.58 g plant^{-1}) was obtained from the control treatment. The root dry matter accumulation of N_2, N_3, N_4, N_5, and N_6 treatments was also increased by 100%, 87.9% ,91.4%, 77.6%, and 60.3%, respectively. The leaf dry matter accumulation varied significantly in response to different levels of fertilizer substitution treatments (table 2). The maximum accumulation of leaf dry matter (0.36 g plant^{-1}) was found in N_1 treatment which was 71.4% increase over the N_0 (control) treatment but statistically identical with N_1, N_2, and N_3 treatments. The lowest leaf dry matter accumulation was (0.21 g plant^{-1}) observed under the control treatment. The N_4, N_5, and N_6 treatments also improved the leaf dry matter accumulation by 61.9%, 52.4% and 57.1%, respectively.

Table 2. Effect of inorganic-organic integrated N management on dry matter accumulation in different plant parts of wheat.

Treatment	Dry matter accumulation in plant parts (g plant^{-1})				
	Root	Leaf	Stem	Spike	Total
N_0	0.58d	0.21c	0.90d	0.69e	1.80f
N_1	1.42a	0.36a	1.50a	1.96a	3.81a
N_2	1.16b	0.35ab	1.48ab	1.72b	3.55b
N_3	1.09bc	0.34ab	1.45abc	1.70bc	3.49bc
N_4	1.11bc	0.34b	1.37abc	1.61c	3.32cd
N_5	1.03bc	0.32b	1.35bc	1.45d	3.12de
N_6	0.93c	0.33b	1.32c	1.40d	3.05e
LSD	0.2130	0.0344	0.1427	0.1112	0.2004
CV	11.63	6.11	6.09	4.22	3.62

Different letter in a column indicates significant variation existed among treatments at 5% level of significance. Here, N_0 = Zero N fertilizer (Control); N_1 = 120 kg N ha^{-1} from Urea; N_2= 100 kg N ha^{-1} from Urea + 20 kg N ha^{-1} from organic manure; N_3= 80 kg N ha^{-1} from Urea + 40 kg N ha^{-1} from organic manure; N_4= 60 kg N ha^{-1} from Urea + 60 kg N ha^{-1} from organic manure; N_5 = 40 kg N ha^{-1} from Urea + 80 kg N ha^{-1} from organic manure; and N_6 = 120 Kg N ha^{-1} from organic manure.

The maximum accumulation of stem dry matter (1.5 g plant^{-1}) of wheat was recorded under the N_1 treatment which was 66.7% increase over the N_0 treatment. The stem dry matter accumulation among N_1, N_2, N_3, and N_4 treatments had no statistical variation. The lowest stem dry matter accumulation (0.90 g plant^{-1}) was found in N_0 treatment. The N_5 and N_6 treatments increased stem dry matter accumulation by 50%, and 46.7%, respectively. The highest spike dry matter (1.96 g plant^{-1}) was achieved from N_1 treatment which was 184.1% greater than N_0 control and significantly improved over other treatments. The N_2, N_3, N_4, N_5, N_6 treatments increased spike dry matter of by 149.3%, 146.4%, 133.3% ,110.1% and 102.9%, respectively. The lowest spike dry matter (0.69 g plant^{-1}) was observed under the N_0 treatment. The total dry matter accumulation The N_1 (120 kg N ha^{-1} from Urea) highest total dry weight of 3.81 g plant^{-1} was recorded in treatment N_1 (120 kg N ha^{-1} from Urea) and the lowest total dry weight of 1.80 (g plant^{-1}) was observed in treatment N_0 .However, total dry matter accumulation of N_2, N_3, N_4, N_5, N_6 treatments which was increased by 97.2%, 93.9% , 84.4% ,73.3% and 69.4% respectively over control though these differences were statistically significant.

In summary, N fertilization from inorganic-organic sources improved dry matter accumulation in selected plant parts likely due to improved nutrient availability and enhanced synthesis and translocation of photosynthates. Greater total dry matter accumulation in wheat occurred when nitrogen was supplied from urea fertilizer. Combined N fertilization from organic and inorganic forms showed gradual reduction with increase in organic share in total fertilizer dose as organic manure mineralizes slowly over long time which might release less available nutrient than urea fertilizer. However, previous found maximum dry matter accumulation in wheat when nitrogen was supplied in combined organic and inorganic forms (Chaudhary et al. 2017, Patel et al. 2018, and Singh et al. 2017).

3.6 Spikelets per spike

Treatments differ statistically in production of spikelets per spike (table 3). The maximum numbers of spikelets per spike (14.89) were observed from the plants treated with N_1 treatment (120 kg N ha^{-1} from Urea) which was 27.7% higher than control treatment but statistically similar to N_2 and N_3 treatment. The minimum number of spikelets per spike (11.66) was observed from the control treatment. The N_2, N_3, N_4, N_5, and N_6 treatments increased number of spikelets per spike by 19.1%, and 15.3%, 9.6%, 7.7%, 7.6% over the control respectively.

3.7 Filled grain per spike

Statistically significant variation existed among the treatments in production of filled grains per spike (Table 3). The highest numbers of the grains per spike (33.67) were found in N_1 treatment which was statistically significant from other treatments. The lowest number of grains per spike (16.33) was observed from the control treatment (Table 4). Compared to control treatment, the N_2, N_3, N_4, N_5 and N_6 treatments increased number of grains per spike by 89.1%, 91.2%, 80.5%, 81.7 % and 79.1%. However, variation among N_2, N_3, N_4, N_5 and N_6 treatments on number of grains per spike were non-significant. Overall, our results indicated that N fertilization from organic-inorganic fertilizer sources increased the grain number per spike (Table 3). The improvement in grain formation per spike under selected fertilization treatment likely due to supply of available N from inorganic and organic sources. Previous studies reported that organic-inorganic N fertilization increases grains per spike (Iqbal et al. 2002, and Arif et al. 2006). It was also reported that increasing the rates of both organic and inorganic fertilizers increases the number of grains produce per spike (Singh et al. 2017; Reddy et al. 2018; Fazily et al. 2021). These findings clearly indicated the role of N in grain formation of wheat.

3.8 1000-grain weight

The thousand (1000) grain weight of wheat varied significantly among the selected chemical to organic fertilizer substitution treatments (Table 3). The maximum thousand grain weight (44.01 g) was observed under N_1 treatment which was statistically identical with N_2, N_3, and N_4 treatments but significantly improved over other treatments. The lowest thousand grain weight of grain (30.57 g) was observed under N_0 treatment. Compared to N_0 treatment (control), the thousand grain weight of N_1, N_2, N_3, N_4, N_5, N_6 treatments increased by 43.9%, 41.3%, 40%, 37.8%, 21.7% and 22.2%, respectively. Previous studies also found significant improvement with nitrogen fertilization where chemical fertilizer was partially substituted with organic fertilizer (kler et al. 2007; Zeidan and Kramany, 2001).

3.9 Grain yield, straw yield, biological yield and harvest index

Grain yield, straw yield and biological yield of wheat showed significant variations in response to selected N fertilization treatments (table 2). The highest grain yield (345.56 g m^{-2}) was recorded under the N_1 treatment (120 kg N ha□¹ from urea), which was statistically similar with N_2 treatment but significantly higher than other treatments and 225.5% increased over control (N_0). The N_2, N_3, N_4, N_5 and N_6 increased grain yield 202.1%, 108.4%, 156.6%, 125.2% and 116%, respectively. The maximum straw yield (422.64 g m^{-2}) was observed with N_1 treatment which was 61.1% greater over N_0 (control) treatment. However, variations among N_1, N_2, N_3, N_4, N_5 and N_6 treatments were statistically non-significant. The highest biological yield (768.21g m^{-2}) was showed from N_1 treatment which was 108% higher than control followed by 97.6% (N_2). The N_3, N_4, N_5 and N_6 treatments resulted in 94.9%, 83.9%, 73.1% and 71.1% increases in biological yield over the control. The lowest biological yield (368.56 g m^{-2}) was observed under N_0 treatment.

Table 3. Effect of inorganic-organic integrated N management on yield and yield contributing characters of wheat.

Treatment	Yield contributing characters			
	Effective tiller plant^{-1}	No. of spikelets spike^{-1}	Filled grain spike^{-1}	1000 grain weight (g)
N_0	1.40 c	11.66 c	16.33 c	30.57 c
N_1	1. 60 a	14.89 a	33.67 a	44.01 a
N_2	1.56 ab	13.89 ab	30.89 b	43.20 a
N_3	1.49 abc	13.44 ab	31.22 b	42.80 a
N_4	1.47 bc	12.78 bc	29.47 b	42.13 a
N_5	1.44 bc	12.56 bc	29.67 b	37.19 b
N_6	1.42 c	12.55 bc	29.25 b	37.35 b
LSD	0.120	1.74	1.996	4.267
CV	4.6	7.62	3.98	6.15

Different letter in a column indicates significant variation existed among treatments at 5% level of significance. Here, N_0 = Zero N fertilizer (Control); N_1 = 120 kg N ha^{-1} from Urea; N_2= 100 kg N ha^{-1} from Urea + 20 kg N ha^{-1} from organic manure; N_3= 80 kg N ha^{-1} from Urea + 40 kg N ha^{-1} from organic manure; N_4= 60 kg N ha^{-1} from Urea + 60 kg N ha^{-1} from organic manure; N_5 = 40 kg N ha^{-1} from Urea + 80 kg N ha^{-1} from organic manure; and N_6 = 120 kg N ha^{-1} from organic manure.

The highest harvest index (HI) of wheat (45.01%) was observed from N_1 treatment (120 kg N ha^{-1} from urea) which was 55.8% greater than control but identical with N_2, and N_3 treatments. The lowest harvest index (28.87%) was observed from N_0 treatment (control). The N_4, N_5, and N_6 treatments also improved the leaf area index by 39.1%, 29.7% and 25.9%, respectively.

Irrespective of nitrogen sources applied, the above selected growth parameters improved significantly over zero N fertilization. Previous studies also reported significant improvements in grain yield and harvest index of wheat with organic-inorganic integrated N fertilization (Singh et al., 2017; Patel et al., 2018; Reddy et al., 2018; Fazily et al., 2021). However, we found a declining trend with increase in organic fertilizer substitution for inorganic N source (urea), indicating that supply of available N was higher from urea fertilizer. It is obvious that organic manure takes long time to mineralize and wheat crop is N thirsty. This antagonistic aspect of nutrient source vs crop nutrient demand likely the main reason for reduction in grain yield, biological yield and harvest index of wheat with organic supplements. Still, low-level substitution of fertilizer N with organic manure (N_2 and N_3 treatments) increased grain yield and HI of wheat close to exclusive N fertilization from inorganic fertilizer (urea).

Table 4. Effect of inorganic-organic integrated N management on grain yield, straw yield, biological yield, harvest index and N use efficiency (NUE) of wheat.

Treatment	Grain yield ($g\ m^{-2}$)	Straw yield ($g\ m^{-2}$)	Biological yield ($g\ m^{-2}$)	Harvest index (%)	NUE ($g\ g^{-1}$)
N_0	106.17 e	262.37 b	368.55 f	28.87 d	-
N_1	345.57 a	422.64 a	768.21 a	45.01 a	28.80 a
N_2	320.76 ab	407.55 a	728.32 ab	44.06 ab	26.73 ab
N_3	297.73 bc	420.79 a	718.53 bc	41.46 abc	24.81 bc
N_4	272.48 c	405.50 a	677.98 cd	40.16 bc	22.71 cd
N_5	239.11 d	398.67 a	637.78 de	37.43 c	19.93 d
N_6	229.27 d	401.29 a	630.56 e	36.36 c	19.11 d
LSD	31.528	37.840	42.273	4.288	3.382
CV	6.96	5.56	3.73	6.03	7.62

Different letter in a column indicates significant variation existed among treatments at 5% level of significance. Here, N_0 = Zero N fertilizer (Control); N_1 = 120 kg N ha^{-1} from Urea; N_2= 100 kg N ha^{-1} from Urea + 20 kg N ha^{-1} from organic manure; N_3= 80 kg N ha^{-1} from Urea + 40 kg N ha^{-1} from organic manure; N_4= 60 kg N ha^{-1} from Urea + 60 kg N ha^{-1} from organic manure; N_5 = 40 kg N ha^{-1} from Urea + 80 kg N ha^{-1} from organic manure; and N_6 = 120 kg N ha^{-1} from organic manure.

4.10. Nitrogen use efficiency (NUE)

The treatments containing N fertilization was considered for the analysis of nitrogen use efficiency of wheat (NUE) excluding the control (N_0) treatment. The highest nitrogen efficiency (28.8 g g^{-1}) of wheat was recorded with N_1 treatment (120 120 kg N ha^{-1} from Urea) identical with NUE of N_2 (26.73 g g^{-1}) improved over rest of the other treatments. The lowest NUE (19.11 g g^{-1}) was observed with N_6 treatment (N_6 = 120 kg N ha^{-1} from OM) which was similar with NUE of N_4 and N_5 treatments. There was no variation in NUE of N_2 and N_3 treatments. Results of this study clearly indicates increase in proportion organic N for chemical N fertilizer (urea) substitution deceases NUE under single-season pot culture ecosystem. Organic manure mineralizes slowly over time and its mineralization is responsive to soil temperature, moisture and inherent soil bio-chemical properties. Therefore, low winter temperature of this experimental site (from mid-November to mid-February) may be one of the key factors for reduced NUE under high level of organic manure substitution treatments (N_4, N_5, and N_6).

4. CONCLUSION

Nitrogen fertilization, regardless of sources applied, significantly improved plant height, leaf area index (LAI), chlorophyll content, effective tiller number, and biomass accumulation of wheat. Application of N_1 treatment (120 kg N ha^{-1} from urea) produced the tallest plants (89.33 cm), highest LAI (4.51), and maximum chlorophyll content of flag leaf. However, N_2 (100 kg N ha^{-1} from urea + 20 kg N ha^{-1} from organic manure) and N_3 (80 kg N ha^{-1} from urea + 40 kg N ha^{-1} from organic manure) treatments performed statistically similar in most growth parameters, indicating that partial substitution of urea fertilizer with organic manure could maintain high productivity of wheat. Nitrogen fertilization enhanced accumulation dry matter in all plant parts, with total dry matter highest in N_1 (3.81 g plant^{-1}). Yield contributing parameters such as effective tillers, spikelets per spike, filled grains per spike, and thousand-grain weight were all significantly improved by nitrogen application. The highest grain yield (345.56 g m^{-2}) and harvest index (45%) were observed under N_1 treatment, but yields from N_2 and N_3 were statistically comparable. NUE was also greatest under N_1 (28.8 g g^{-1}), closely followed by N_2 (26.73 g g^{-1}), indicating efficient nitrogen utilization with low-level organic manure substitution. Overall, increasing organic manure beyond N_3 treatment (40% substitution) gradually reduced yield and NUE likely due to slower nutrient release from organic sources. The study concludes that one-third portion of urea nitrogen could be substituted of with organic manure to optimize wheat growth and yield under subtropical monsoon conditions of Bangladesh. This integrated nutrient management approach can enhance nitrogen use efficiency, sustain productivity, and reduce environmental risks associated with excessive chemical fertilizer use.

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