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Evaluation of wheat (*Triticum aestivum*) genotypes for higher yield and enhanced nitrogen use efficiency in Indo-Gangetic Plains

SANDEEP GAWDIYA[1]*, DINESH KUMAR[1] and Y S SHIVAY[1]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

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ABSTRACT

Extensive research has been conducted on various nitrogen (N) management approaches to fulfil the growing needs of cereals while enhancing the efficiency of agricultural resource utilization. Nevertheless, the intensive agricultural model continues to prioritize the achievement of high crop yields and improving nitrogen use efficiency (NUE) as opposing targets. The primary aim of this study was to investigate whether a corresponding increase in N application is necessary to achieve higher crop yields. The study evaluated the effects of 3 N treatments (N0, N75, and N150) on 10 wheat (*Triticum aestivum* L.) genotypes during 2020–21 and 2021–22 at research farm of ICAR-Indian Agricultural Research Institute, New Delhi. In both growing seasons, the highest grain yield (GY) of 5.3 t/ha, agronomic efficiency (AE_N) of 28.7 kg grain/kg N, and partial factor productivity of applied N (PFP_N) of 60.2 kg grain/kg N were obtained by the HD 3249 genotype, followed by HD 3117. The application of N75 and N150 increased grain yields by 72.3 and 142.6%, respectively, over N0. Significant relationships were observed between GY, PFP_N and AE_N at all N levels, and a decreasing trend was observed in both PFP_N and AE_N as the N application rate increased. The study results suggest that the adoption of genotype-specific nitrogen (N) rates could provide a mutually beneficial solution to meet the growing demand for food while improving NUE. Overall, based on GY and $AE_{N,}$ the research findings indicate that the genotypes HD 3249 and HD 3117 are efficient candidates for N use, with the potential for higher yields and NUE in the Indo-Gangetic plains of India.

Keywords: Genotype-nitrogen rates, Grain yield, Nitrogen management, N-use efficiency, Wheat genotypes

The excessive use of nitrogen (N) in cereal crops is a global phenomenon. However, the low N recovery efficiency in cereals, which is less than 35%, has raised concerns due to the severe negative environmental consequences caused by the remaining N (Raun and Johnson 1999, Hirel *et al.* 2007, Xu *et al.* 2012). To address these challenges, a potential option is to increase productivity by adopting cultivars that have good genetic potential for N use (Reynolds *et al.* 2012). One of the best approaches to achieve the objective of high production of wheat (*Triticum aestivum* L.) is to improve crop yields on existing farmland with suitable genotypes. Unfortunately, over the past 20 years, the rate of increase in economic yield of wheat is only 0.9% per year (Ray *et al.* 2013). To achieve higher wheat yields, the crop must meet the high N requirements, which typically leads to proportional increase in N fertilizer usage. Mueller *et al.* (2012) stated that 9% increase in the use of N fertilizers would be needed to bridge the yield gaps of the main cereals (rice, wheat, and maize) and achieve a 30% increase in production in the coming decades. It remains unclear whether this conclusion is relevant to wheat cultivation in India, where farmers use excessive N fertilizer to achieve high grain yields, resulting in decreased nitrogen use efficiency (NUE). More field research is needed to evaluate the possibility of boosting crop yield and whether it necessitates a proportional increase in N fertilizer application.

The regions of India with high wheat production have the most intense application of N in the country. It is possible to decrease the fertilizer N usage while maintaining high grain yield and enhancing NUE through genotypes that have genetic potential to high N absorption and assimilation (Tian *et al.* 2018, Wang *et al.* 2012a, Wang *et al.* 2012b). So, still large gaps are available to compares various N rates for different genotypes to enhance both yield and NUE. Therefore, this study was carried out to assess the various N inputs on winter (*rabi*) wheat for determining optimal N rate, yield and NUE.

MATERIALS AND METHODS

The research experiments were conducted during 2020–21 and 2021–22 at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi. The field weather was characterized by cool and temperate. The average maximum and minimum temperatures recorded in the regions ranged between 17–38°C and 7–17°C,

[1]ICAR-Indian Agricultural Research Institute, New Delhi.
*Corresponding author email: dineshctt@yahoo.com

respectively. Moreover, the mean precipitation during cropping season is 181.5 mm.

Experimental design and crop management: The experiment involved 3 different nitrogen treatments (main plot) and 10 wheat genotypes (HD-3226, HDCSW-18, HD-2967, HD-3086, HD-3249, HD-2733, PBW-550, PBW-34, HD-3117, HD-3298-subplot) that were assigned to plots in a split plot design. The 3 N-rate treatments included N0 (no nitrogen-NN), N75 (75 kg N/ha low nitrogen-LN) and N150 (150 kg N/ha-high nitrogen-HN). Before sowing, basal fertilizers such as phosphorus (60 kg P_2O_5/ha) and potash (60 kg K_2O/ha) were applied, while nitrogen was applied in 3 separate splits. Half of the nitrogen was applied as basal, $1/4^{th}$ during the crown root initiation stage [20–25 DAS (days after sowing)], and the remaining $1/4^{th}$ during the tillering stage (40–45 DAS). The fields were irrigated 6 times by flood irrigation. The effects of the 3 N treatments on wheat genotype yield and nitrogen use efficiency (NUE) were analysed and compared between the different genotypes.

Sampling: After reaching maturity, 3–4 m^2 areas in each plot were used for manual harvesting, threshing and measurement of yield. Subsequently, the grain was dried to a constant weight in an oven set at 70°C and maintained a moisture content of 12.5% in the grains.

Calculation of N-use efficiencies: The N-use efficiencies (agronomic efficiency- AE_N and partial factor productivity-PFP_N) were calculated as:

AE_N = Grain yield (kg/ha) in fertilized plot – grain yield in control plot)/rate of N application (kg/ha)

PFP_N= yield (kg/ha) / Rate of N application (kg/ha)

Data Analysis: Statistical analysis of all data was performed using the open-source available statistical software R Studio [agricolae package of R Version (Mendiburu 2021)]. For comparisons of multiple means Duncan's method are used, with an alpha probability level of 0.05. The 'performance analytics' packages in R studio (2021) were used to create a Pearson's correlation coefficient matrix or diagram, utilizing the recorded crop traits data spanning over two years.

RESULTS AND DISCUSSION

Grain yield and NUE under 3 N levels: Over 2 years, N rate, and genotypes significantly influenced the yields (Table 1, Fig 1). Genotypes grown under N150 (HN) had a significantly higher average yield (5.92 t/ha) than those grown under N75 (LN) (4.21 t/ha) and N0 (2.44 t/ha) across both years. The N levels LN and HN had mean yield increases of 72.3% and 142.6%, respectively, compared to N0 (NN) ($P<0.05$). AE_N was comparable between LN and HN, but PFP_N was significantly higher at LN than HN ($P<0.05$) (Table 2). Furthermore, the increase in N

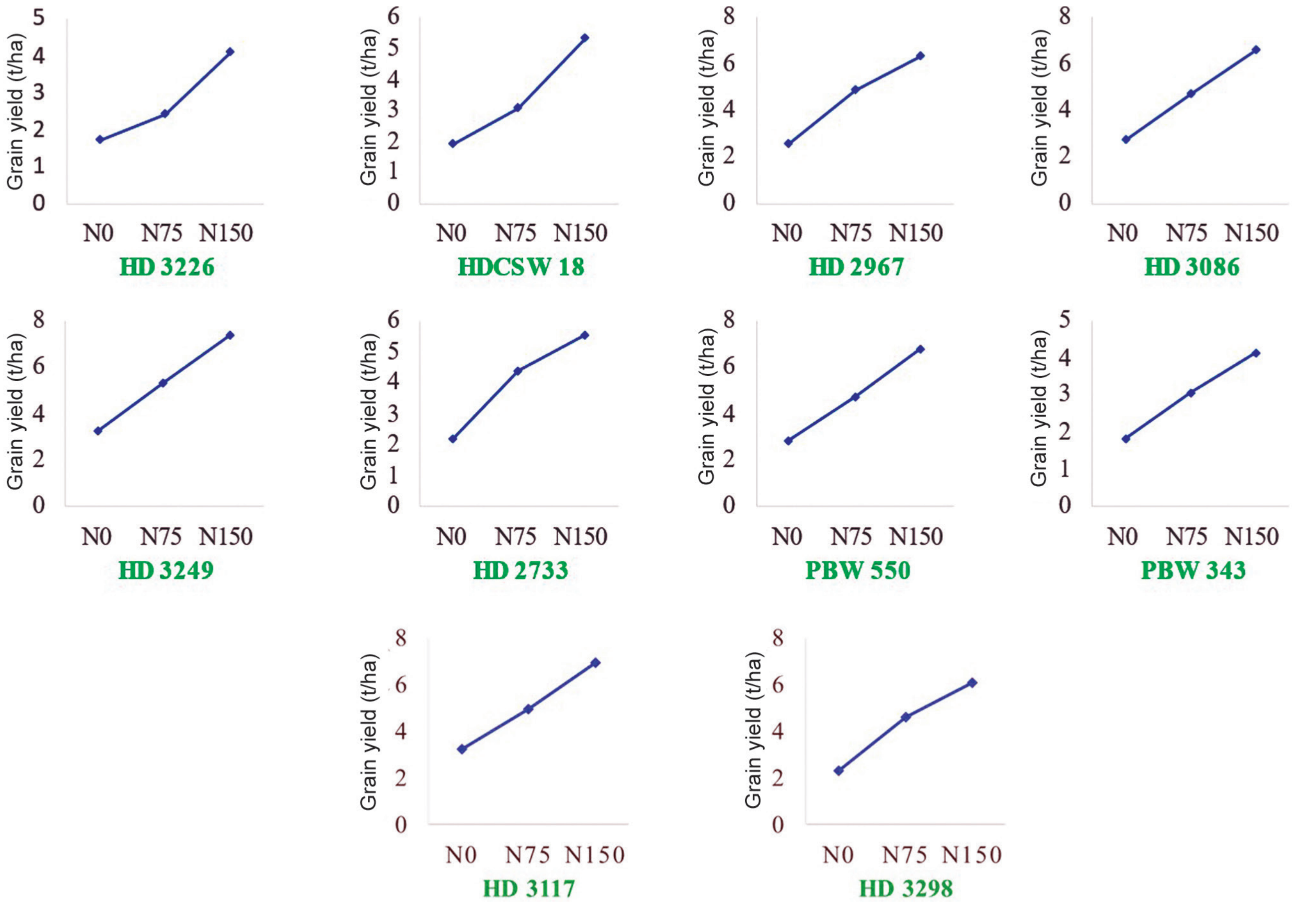

Fig 1 Grain yield performance and trends of 10 wheat genotypes over 2 years under 3 different nitrogen levels. [N0-NN (no nitrogen), N75-LN (low nitrogen), N150-HN (high nitrogen)]

Table 1 Two-year pooled analysis data of the nitrogen × genotype interaction and its effect on wheat grain yield

Nitrogen × variety	HD 3226	HDCSW 18	HD 2967	HD 3086	HD 3249	HD 2733	PBW 550	PBW 343	HD 3117	HD 3298	Mean
N0	1.68^{p}	1.93^{op}	2.50^{lmn}	2.67^{lm}	3.24^{j}	2.17^{no}	2.83^{kl}	1.85^{op}	3.24^{j}	2.30^{n}	2.44^{c}
N75	2.41^{Mn}	3.09^{Jk}	4.88^{G}	4.65^{Gh}	5.33^{f}	4.38^{hi}	4.70^{gh}	3.07^{jk}	4.94^{g}	4.61^{gh}	4.20^{b}
N150	4.06^{i}	5.32^{f}	6.34^{de}	6.60^{cd}	7.39^{a}	5.56^{f}	6.79^{bc}	4.15^{i}	6.95^{b}	6.06^{e}	5.92^{a}
Mean	2.70^{i}	3.40^{g}	4.60^{d}	4.60^{cd}	5.30^{a}	4.00^{f}	4.80^{c}	3.00^{h}	5.00^{b}	4.30^{e}	
*N × V = 0.45 (SEm± = 0.15) / *V × N = 1.70 (SEm± = 0.31)											

*LSD (P=0.05) for nitrogen means at same or different level of varieties; *LSD (P=0.05) for varieties means at same or different level of nitrogen; Values in a column followed by the different letters was significantly different at P<0.05 as determined by LSD; Letters indicate the comparison among genotypes under different N levels.

significantly reduced PFP_N under both LN and HN.

Maximum yield of genotypes at different N levels: The HD 3249 and HD 3117 genotypes outperformed other genotypes in terms of the response to grain yield (GY) at all levels of N (NN, LN, HN) (Fig 1 and Table 1). On average, the maximum GY for HD 3249 and HD 3117 was 5.3/t ha and 5/t ha, respectively. Genotype HD 3226 yielded the lowest at 2.7 t/ha, while all genotypes responded up to the N level N120, although with varying grain yield results (Fig 1). Selecting genotypes that are suitable for specific areas, based on soil fertility and weather conditions, is crucial to improving both GY and nitrogen use efficiency (NUE), thus reducing the negative effects of N fertilizers. The calculated average optimal N rate for wheat genotypes was 150 kg N/ha to achieve maximum GY.

Factors driving maximum yield and high NUE: For determination of LN and HN rates effects on wheat NUE, PFP_N and AE_N values were correlated with GY (Fig 2). Pearson's correlation analysis revealed highly significant positive correlation between grain yield, AE_N and PFP_N at mean levels of N, as well as LN and HN (P<0.001), and significant correlation between the mean N yield and partial factor productivity (PFP) at P<0.01.

A significant area of focus in modern agricultural

Table 2 Effect of nitrogen fertilization on nitrogen-use efficiencies of wheat

Nitrogen × variety	Agronomic efficiency (Per kg grain yield increased/kg N applied)			Partial factor productivity (Per kg grain/kg N applied)		
	2020–21	2021–22	Pooled	2020–21	2021–22	Pooled
N0	-	-	-	-	-	-
N75	23.4^{a}	23.6^{a}	23.5^{a}	55.8^{a}	56.3^{a}	56.0^{a}
N150	23.2^{a}	23.2^{a}	23.2^{a}	39.4^{b}	39.6^{b}	39.5^{b}
SEm±	2.2	2.3	2.3	0.23	0.25	0.24
CD (P= 0.05)	6.7	6.8	6.8	4.20	4.24	4.23
HD 3226	14.3^{d}	11.2^{c}	12.8^{i}	30.7^{h}	28.4^{e}	29.6^{j}
HDCSW-18	23.2^{bc}	14.9^{c}	19.0^{g}	42.9^{f}	33.7^{d}	38.3^{h}
HD 2967	28.1^{a}	27.5^{ab}	27.8^{b}	50.5^{d}	56.8^{ab}	53.7^{d}
HD 3086	25.1^{ab}	27.6^{ab}	26.3^{c}	52.2^{cd}	53.8^{bc}	53.0^{e}
HD 3249	25.1^{ab}	32.2^{a}	28.7^{a}	60.0^{a}	60.3^{a}	60.2^{a}
HD 2733	24.2^{b}	27.7^{ab}	26.0^{d}	45.5^{e}	49.9^{c}	47.7^{g}
PBW 550	25.3^{ab}	25.9^{b}	25.6^{e}	53.2^{bc}	54.6^{b}	53.9^{c}
PBW 343	20.4^{c}	11.3^{c}	15.9^{h}	38.4^{g}	30.2^{de}	34.3^{i}
HD 3117	22.8^{bc}	24.6^{b}	23.7^{f}	54.8^{b}	57.4^{ab}	56.1^{b}
HD 3298	24.5^{b}	31.4^{a}	28.0^{b}	47.5^{e}	54.4^{b}	50.9^{f}
SEm±	1	1.8	1.3	3.6	3.6	0.98
CD (P= 0.05)	3	5.4	2.8	10.7	10.7	2.92
Interaction	ns	ns	ns	ns	ns	ns

*LSD (P=0.05) for nitrogen means at same or different level of varieties; *LSD (P=0.05) for varieties means at same or different level of nitrogen; Values in a column followed by the different letters was significantly different at P<0.05 as determined by LSD; Letters indicate the comparison among genotypes under different N levels.

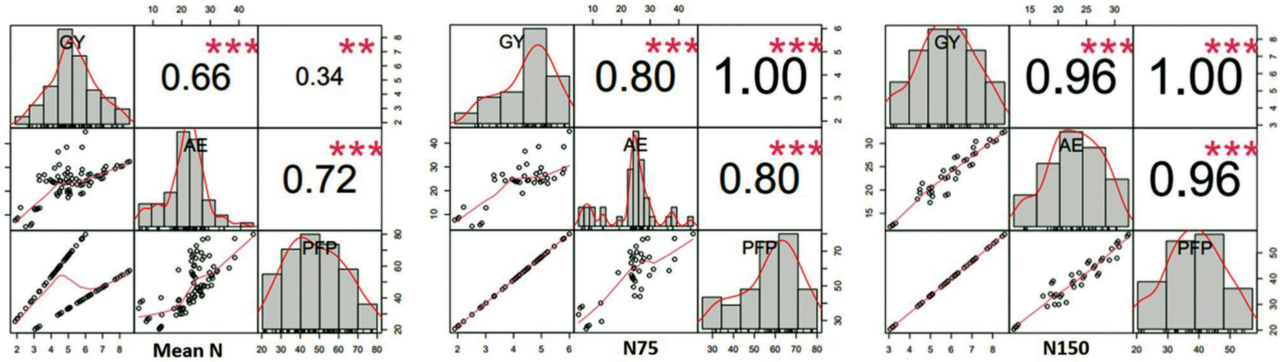

Fig 2 Pearson's correlation among crop traits/parameters of 10 wheat genotypes under mean N (mean of all nitrogen levels). GY, Grain yield; AE; Agronomic efficiency, PEP, Partial factor productivity.
The correlation coefficient (r values) was calculated from mean of two-years data from 2020–21 to 2021–22. ***, highly significant (P<0.001); **, moderately significant (P<0.01); *, significant (P<0.05). Diagonals indicates how each parameter is distributed. In bottom of diagonal scatter plots with lines are available. At the top of diagonals values of correlations and significance level are available. Size of correlation values and intensity of colour are showing correlation coefficients.

research is to improve NUE without sacrificing wheat yield by reducing N application. Genotypes HD 3249 and HD 3117 shows higher wheat GY highlights the importance of their high yield potential under the same levels of N, making them more suitable choices in all aspects compared to other genotypes. In this study, the use of appropriately adapted cultivars with optimal N rates showed potential to improve the available N uptake and increase the plant N conversion to GY. Our findings match with Voss-Fels *et al.* (2019), who reported that optimal N rates and genotypes with high genetic potential for NUE could improve winter wheat yields. The findings of Hameed *et al.* (2019) also support our results, indicating that selecting the appropriate dose and cultivar of N can reduce N losses, providing a chance to decrease N application while improving NUE. In fact, genotype-specific N management played a crucial role in determining NUE. For example, based on the pooled analysis data, genotype HD 3249 shows an average PFP_N of 60.2 kg/kg and AE_N of 28.7 kg/kg. Similar results were reported by Good *et al.* (2011), who found that the genetic potential of a genotype significantly influences the improvement of NUE. The greater efficiency of N use observed in certain genotypes may be attributed to the effectiveness of their root systems in efficiently utilizing available N resources (Cassman *et al.* in 2002). Among the nitrogen levels tested, N150 shows highest NUE and GY. This could be reason behind the genetic makeup of the selected genotypes, which have the inherent ability to respond more effectively to higher levels of N (Duan *et al.* 2020). A key strategy to improve both wheat GY and NUE is to adopt cultivars that are well adapted region-specific weather conditions. Myagkikh *et al.* (2021) support this notion, stating that selecting a cultivar that is adaptable to the agroclimatic conditions of a particular region is a primary approach to generate stable grain yield with desired quality characteristics. Therefore, it is important to evaluate cultivar performance at various agronomic research centres.

The application of HN does not always result in higher crop yields, as the law of diminishing returns suggests (Cassman *et al.* 2002), leading to reduced NUE in crop production systems. This study revealed that N levels N75 and N150 increased the GY of all genotypes by 72.3 and 142.6%, respectively, compared to N0. Optimizing the timing and rates of nitrogen (N) fertilizer application in agriculture can not only increase crop yields but also minimize N loss to the environment (Liu *et al.* 2019).

Based on the results, it can be observed that the GY of the genotypes exhibited a positive correlation with the N levels applied until the highest N rate was reached in the 3 N treatments (Fig 2). Under field conditions, farmers frequently apply excessive amounts of N fertilizer to crops for achieving high yield per unit area, despite the inherent inefficiencies associated with this practice and different genotypes (Cui *et al.* 2008a, 2008b). Furthermore, a lack of knowledge regarding the appropriate N application rate often leads farmers to apply excessive N to prevent low crop yields (Zhang *et al.* 2011). Based on our findings, the ideal N rate for the genotypes HD 3249 and HD 3117 was 150 kg N/ha, suggesting that farmers can achieve their yield targets and improve NUE by reducing N fertilizer input while following this recommendation. Therefore, location-specific genotype selection and N application rates must be taken into account to enhance agricultural production performance. (Cai *et al.* 2021).

The N0 plot yield indicates the performance of genotypes under conditions of no external N supply and the nutrient supply capacity of soil (Cui *et al.* 2008a, Wang *et al.* 2012a, Wang *et al.* 2012b). This suggests some of the potential for higher yields in the NN genotype compared to LN and HN. Similarly, positive correlations between wheat GY and various levels of nitrogen input were reported by Valkama *et al.* (2013) and Gaudin *et al.* (2015). The findings of this study indicate that the selection of genotypes that exhibit high GY and NUE at equivalent levels of N is critical in identifying superior genotypes. As the N rate increased, PFP_N and AE_N exhibited a decreasing trend. This statement agrees with Rahimizadeh *et al.* (2010), who reported a reduction in NUE with increasing N rate.

The present investigation has identified genotypes HD 3249 and HD 3117 with N150-splits having high yield and NUE in New Delhi, India. The findings of this study support the notion that the cultivation of locally adapted cultivars can optimize grain yield while minimizing the negative environmental impacts arising from excessive nitrogen loss. Consequently, the adoption of such cultivars is recommended. Effective dissemination of scientific knowledge to farmers and timely application of appropriate dose of N dosages with the right genotype are recommended to improve wheat yield and NUE in the future. Furthermore, these genotypes are important to utilize for breeding purposes. To ensure food security and prevent the adverse environmental impacts resulting from excessive N loss due to external N applications, it is imperative to adopt a vital strategy that involves achieving sustainable crop growth and enhancing NUE in farmer fields.

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