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Nitrogen levels effect on wheat nitrogen use efficiency and yield under field conditions

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A two year (2009-10 and 2010-11) field experiment was conducted on twelve wheat genotypes supplied with four levels of nitrogen (recommended dose of nitrogen; RDN, RDN-50%, RDN-25% and RDN+25%) to identify genotypes with maximum nitrogen use efficiency. Physiological parameters namely plant height, tiller number, spikelet number, grain yield, thousand grain weight and biomass increased with increases in nitrogen dose. During both years, yield and nitrogen use efficiency were higher in PBW 621 and PBW 636 while BW 9022 showed maximum thousand grain weight over other genotypes. Among all genotypes, HD 2967 was the tallest and tiller number and spikelet number were maximum in BW 9183.

Key words: Nitrogen, yield, nitrogen use efficiency, wheat, genotypes.

INTRODUCTION

Nitrogen (N) is an essential element for both crop development and biomass. The absorption of N by plants plays an important role in their growth. However, excessive use of N is economically costly (Ju et al., 2009) as well as environmentally damaging with excess N lost by leaching into groundwater and runoff into surface water (Galloway et al., 2008; Gruber and Galloway, 2008; Conley et al., 2009). Both to avoid pollution by nitrates and to maintain economic balance, there is need to identify genotypes that can efficiently use N. Efficient use of N by wheat is needed to sustain or increase yield and quality, while reducing the negative impacts of fertilizer on the environment (Hirel et al., 2007; Foulkes et al., 2009).

Assimilation of inorganic N into organic form has a marked influence on plant productivity and crop yield. Grain yield is the main target of crop production. Adequate N nutrition is required for full development of tillers and leaves. Rahman et al. (2011) reported that N application has a tremendous effect on tiller formation and survival of tillers. Application of N at later stages of maize (Amanullah et al., 2009) increased plant height, kernel number and high biomass at maturity that results in high yield (Amanullah et al. 2009, Hokmalipour et al., 2010). Nitrogen use efficiency (NUE) is defined as the grain yield per unit of available N in the soil (Moll et al., 1982). NUE varies with the growth stage of the plant (Woolfolk et al., 2002). NUE as reflected in grain yield of winter wheat has also been shown to change with time and rate of application (Woolfolk et al., 2002). Grain yield and N content of cereal crops increase significantly with applied N (Viller and Guillaumes, 2010).

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Efficient N utilization is crucial for economic wheat production and protection of ground and surface water (Vukovic et al., 2008). The genetic variation in both acquisition and internal-use efficiencies indicates that there is potential for increases in efficiency of nitrogen use through plant selection, particularly in low nitrogen environments (Giller et al., 2004). There is a need to increase NUE of cereal crops by selecting new hybrids or cultivars from the available ancient and modern germplasm collection. These objectives can be met through identification of varieties that have better NUE while at least maintaining or optimally increasing crop productivity. Field-based studies have shown differences in the NUE of barley genotypes by Abeledo et al. (2008) and Anbessa et al (2009). The study was conducted under field conditions over two years with the objective to assess the effect of different doses of N on wheat yield and yield related traits and to identify genotype that possesses high yield and NUE.

MATERIALS AND METHODS

Two year (2009-10 and 2010-11) experiment was conducted on the fields of Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana (30.91°N, 75.85°E and 252 m asl), India. to study the response of twelve wheat genotypes namely PBW 621, PBW 636, PBW 590, DBW 17, HD 2967, PBW 509, BW 9178, BW 9183, BW 8989, BW 9022, PBW 343 and PBW 550 to four doses of N fertilizer. The crop was sown in plots consisting of 4 rows of 1 m each in 22.5 cm spaced rows and with 40 cm between the plots. The experimental design was a split plot plots with three replicates. The crop was raised under normal planting time, that is, 28th October, 2009 and 29th October, 2010 in the field under 4 different N levels (in the form of urea) including the presently recommended N dose (RDN) (120 Kg N/ha), two suboptimal N doses [RDN-50% (60 Kg N/ha) and RDN-25% (90 Kg N/ha)] and supra-optimal N dose [RDN+25% (150 Kg N/ha)]. NPK and Diammonium Phosphate were applied as basal dose and urea was applied in different doses as described earlier. N dose was added in two split applications: First at the time of sowing and second at 1st irrigation (almost month after sowing). In the results, mean values of both years are discussed.

Grain yield was determined by recording the yield after shelling. The grain yield of each plot was recorded and expressed as kg/m^2. Biomass was determined by taking the weight of above ground dried plants along with the ears. The biomass was expressed as kg/plant. Thousand grain weight was calculated by randomly selecting sample from the pool of harvested seeds from each plot. NUE was calculated by the formula given by Moll et al. (1982):

$$\text{NUE} = \frac{\text{Grain yield}}{\text{Nitrogen fertilizer application}}$$

Statistical analysis

All the values were mean of three replicates. Data obtained was subjected to split plot design at 5% level of critical difference using CPCS1 software developed by department of Statistics, Punjab Agricutural University, Ludhiana.

RESULTS AND DISCUSSION

Yield and yield attributes

Mean values of both years showed an increase in grain yield and its attributes supplied with higher doses of N. Results showed that yield was in the range of 0.306 to 0.563 Kg/m^2 (Table 1). The effect of genotypes- N levels interaction was significant and for all genotypes, yield was significantly affected by N levels. As reported earlier, grain yield is significantly influenced by N application (Singh et al., 2000; Sial et al., 2005). As compared to recommended dose (RDN), under low N levels viz. RDN-50% and RDN-25%, the reduction in yield was 41 and 9%, respectively. Increased grain yield with increase in N application could be ascribed to increased biomass production with N fertilization.

Ample nutrient supply results in enhancement in growth and production of more reproductive structures per plant (that is, tiller number – Table 2) thereby increasing overall yield of the crop as reported by Lawlor (2002) and Valerol et al. (2005). Genotype PBW 621 significantly produced greatest grain yield at RDN-50% (0.385 Kg/m^2) and RDN-25% (0.605 Kg/m^2), RDN (0.625 Kg/m^2) while at RDN+25%, two genotypes PBW 621 and PBW 636 gave the highest yields (0.635 Kg/m^2). Genotype BW 8989 gave very low yield (0.306 Kg/sqm).

There was 6 and 2% decrease in thousand grain weight with the application of RDN-50% and RDN - 25%, respectively as compared to optimum N dose (Table 1). The low N supply decreases grain weight due to less supply of the grain with carbohydrates and amino compounds during the lag phase when the number of storage cells and starch granules are being formed as reported by Paponov et al. (2005). Thousand grain weight was in the range of 31.51 to 37.21 g and the maximum thousand grain weight of 35.64 g (RDN-50%), 36.64 g (RDN-25%), 37.83 g (RDN) and 38.72 g (RDN+25%) was recorded for the genotype BW 9022 as depicted in Table 1. The interaction of genotypes and N levels showed significant differences in thousand grain weight. As observed in our study, reports in the literature also indicate that thousand grain weight increases with increasing dose of N in wheat (Gouis et al., 2000; Guarda et al., 2004) and corn (Hokamlipour et al., 2010).

As compared to optimum N dose, the average decrease in biomass at RDN-50% and RDN-25% was 25 and 8%, respectively. The highest biomass was recorded in the treatment RDN+25% (Table 1). Similar to our observations, biomass increased significantly with increasing N level as reported in corn and sweet sorghum by Almodares et al. (2009). Biomass varied in the range of 1.32 to 1.84 Kg/plant (Table 1). In genotypes, PBW 621 and PBW 343 at RDN-50% (1.29 Kg/plant) and in PBW 636 at RDN-25%, RDN and RDN+25%, the largest biomasses were recorded. Results indicated that decrease in biomass was proportional with the decrease

Table 1. Effect of different doses of nitrogen on yield (Kg/sqm), thousand grain weight (g) and biomass (Kg/plant) during years and 2009-10 and 2010-11.

N Doses / Genotypes	Yield (Kg/m^2)					Thousand grain weight (g)					Biomass (Kg/plant)				
	RDN-50%	RDN-25%	RDN	RDN+25%	Mean	RDN-50%	RDN-25%	RDN	RDN+25%	Mean	RDN-50%	RDN-25%	RDN	RDN+25%	Mean
PBW 621	0.385	0.605	0.625	0.635	0.563	32.64	33.31	34.00	34.78	33.68	1.27	1.44	1.70	1.99	1.60
PBW 636	0.350	0.530	0.545	0.635	0.515	32.87	33.45	34.36	34.64	33.83	1.29	1.79	1.96	2.34	1.84
PBW 590	0.320	0.435	0.455	0.470	0.420	33.29	34.53	35.73	36.92	35.11	1.17	1.44	1.50	1.64	1.44
DBW 17	0.280	0.415	0.470	0.485	0.413	31.72	32.92	34.26	36.34	33.81	1.14	1.40	1.54	1.89	1.49
HD 2967	0.295	0.410	0.450	0.480	0.409	33.50	35.95	36.85	37.89	36.05	1.08	1.44	1.48	1.97	1.49
PBW 509	0.240	0.300	0.480	0.510	0.383	34.03	35.28	35.50	36.73	35.38	1.27	1.43	1.54	1.67	1.47
BW 9178	0.195	0.375	0.390	0.485	0.361	32.73	33.66	34.31	37.06	34.44	1.17	1.54	1.68	1.87	1.56
BW 9183	0.215	0.330	0.360	0.410	0.329	33.50	34.47	34.64	36.27	34.72	1.17	1.73	1.80	1.99	1.67
BW 8989	0.200	0.310	0.335	0.380	0.306	34.87	35.47	35.67	36.59	35.65	1.02	1.20	1.30	1.77	1.32
BW 9022	0.190	0.360	0.375	0.405	0.333	35.64	36.64	37.83	38.72	37.21	1.25	1.39	1.68	1.90	1.55
PBW 343	0.205	0.325	0.355	0.440	0.331	29.34	31.50	32.39	32.81	31.51	1.29	1.37	1.55	1.77	1.49
PBW 550	0.215	0.395	0.415	0.465	0.373	32.78	33.92	35.66	35.78	34.53	1.22	1.57	1.64	1.92	1.58
Mean	0.258	0.399	0.438	0.483	0.395	33.08	34.26	35.10	36.21	34.66	1.20	1.48	1.61	1.89	1.54

CD (5%): A- 0.012, B- 0.020, AB- 0.041; A- 0.984, B- 1.704, AB- 1.964; A- 0.118, B- 0.204, AB- 0.738; A- N doses, B-Genotypes, AB-In.

Table 2. Effect of different doses of nitrogen tiller number (per m row length) and spikelet number during years 2009-10 and 2010-2011.

N Doses / Genotypes	Tiller number (per m row length)					Spikelet number				
	RDN-50%	RDN-25%	RDN	RDN+ 25%	Mean	RDN-50%	RDN-25%	RDN	RDN+ 25%	Mean
PBW 621	81	84	89	95	87	17	19	19	20	19
PBW 636	80	84	99	102	91	18	18	20	21	19
PBW 590	61	75	84	86	76	15	18	17	19	17
DBW 17	69	82	78	95	81	18	18	18	19	18
HD 2967	62	80	88	91	80	18	18	19	20	19
PBW 509	68	81	83	94	81	17	18	18	18	17
BW 9178	72	87	96	98	88	16	18	18	18	17
BW 9183	69	87	93	99	87	18	19	19	19	19
BW 8989	66	66	79	95	76	18	19	19	19	19
BW 9022	69	82	85	95	82	18	18	19	19	18
PBW 343	72	76	85	87	80	17	17	18	18	18
PBW 550	71	76	79	87	78	16	18	18	19	17
Mean	70	80	87	94	82	17	18	19	19	18

CD (5%): A- 5.100, B- 8.828, AB- 13.224; A- 0.555, B- 0.962, AB- 1.567; A- N doses, B-Genotypes, AB-Interaction.

Table 3. Effect of different nitrogen doses on variation in nitrogen use efficiency (NUE) (Kg Kg^{-1}) during years 2009-10 and 2010-11.

N Doses / Genotypes	NUE (Kg Kg^{-1})				
	RDN-50%	**RDN-25%**	**RDN**	**RDN+ 25%**	**Mean**
PBW 621	64.2	67.3	50.9	42.0	56.1
PBW 636	58.4	58.9	45.4	42.4	51.3
PBW 590	53.4	48.4	37.9	31.4	42.7
DBW 17	46.7	46.1	39.2	32.3	41.1
HD 2967	49.2	45.6	37.5	32.0	41.1
PBW 509	40.0	33.4	40.0	34.0	36.8
BW 9178	32.5	41.7	32.5	32.4	34.8
BW 9183	35.9	36.7	30.0	27.4	32.5
BW 8989	34.2	36.1	29.6	29.4	32.3
BW 9022	31.7	40.0	31.3	27.0	32.5
PBW 343	33.4	34.5	28.0	25.4	30.3
PBW 550	35.9	43.9	34.6	31.0	36.3
Mean	39.0	40.2	33.6	29.7	35.6

CD (5%): A- 1.527, B- 2.646, AB- 5.291; A- N doses, B-Genotypes, AB-Interaction.

in sub optimal dose of N. Thousand grain weight and biomass were significantly affected by different N levels but no significant difference was found between control (RDN) and RDN-25% (Table 1).

At RDN+25%, tiller number was maximum while minimum tiller number was recorded in treatment RDN-50% (Table 2). The increase in number of fertile tillers with the increasing levels of N can be attributed to the reduction in mortality of tillers and enabling the production of more tillers from the main stem (Warraich et al., 2002). Tiller number was found to lie in the range of 76 to 91 (Table 2) and highest number was recorded in PBW 621 at RDN-50% (81) and in BW 9178 and BW 9183 at RDN-25% (87), respectively. There was a marginal decrease in spikelet number at RDN-50% and RDN-25%, respectively. PBW 621, PBW 636, DBW 17, HD 2967, BW 9183, BW 8989 and BW 9022 showed maximum spikelet number at lower N doses (Table 2). Spikelet number was affected significantly by different N levels and significant difference was found between treatment RDN-50% and RDN-25% as compared to control.

Nitrogen use efficiency (NUE)

Nitrogen use efficiency is based on yield performance, that is, on grain yield per N input. During both years (2009-10 and 2010-11) of study, genotypic variation for NUE was observed, however, it decreased with increasing dose of N. A decrease in NUE with increasing fertilizer rates is due to less increase in grain yield in comparison to N supply as observed by Zhao et al. (2006) in sorghum. Beatty et al. (2010) reported that the NUE of barley genotypes grown in field depends on the level of N supplied.

Nitrogen use efficiency varied from 30.3 to 56.1 Kg Kg^{-1} as shown in Table 3. Highest NUE was recorded in PBW 621 at both RDN-50% (64.2 Kg Kg^{-1}) and RDN-25% (67.3 Kg Kg^{-1}). Several studies on maize have shown genetic variability for NUE both at low and high N fertilization levels (Presterl et al., 2002; Gallais and Coque, 2005). Between N treatments, maximum NUE was recorded in RDN-25% which was significantly higher than that of control (RDN) but it was statistically close to RDN-50%. Main focus of our study was not to deprive plants for nutrients but to find a N dose up to which N fertilization can be reduced with high yield and NUE. This study confirmed that recently released cultivar by PAU viz. PBW 621 is high yielding and is also efficient in metabolizing N.

Correlation analysis between different physiological traits and NUE indicated that NUE was positively and significantly correlated with grain yield at all the four levels of applied N for all genotypes. However, the relationship of other physiological traits, that is, thousand grain weight, biomass, plant height, tiller number and spikelet number was non-significant. Positive and significant correlation was observed between biomass and tiller number (Table 4).

Mean values for studied parameters of twelve genotypes during first year (2009-10) and second year (2010-11) were grouped into clusters on the basis of all studied physiological parameters. A cluster tree was generated using NTSYS software (Rohlf, 1998). Combined cluster analysis of both years showed that 12 genotypes were divided into three clusters (I, II and III) (Figure 1). In the cluster I, PBW 621 and PBW 636 were clustered together. In Cluster II, PBW 590 and HD 2967 while in cluster III, DBW 17, PBW 550, PBW 509, BW

Table 4. Correlation analysis between different yield attributes in wheat genotypes.

Parameter	Yield	Thousand grain weight	Biomass	Plant height	Tiller number	Spikelet number
NUE	0.982	-0.163	0.447	0.201	0.418	0.301
Yield		-0.243	0.499	0.273	0.468	0.248
Thousand grain weight			-0.230	-0.308	-0.232	-0.013
Biomass				0.341	0.840	0.257
Plant height					0.443	0.373
Tiller number						0.325

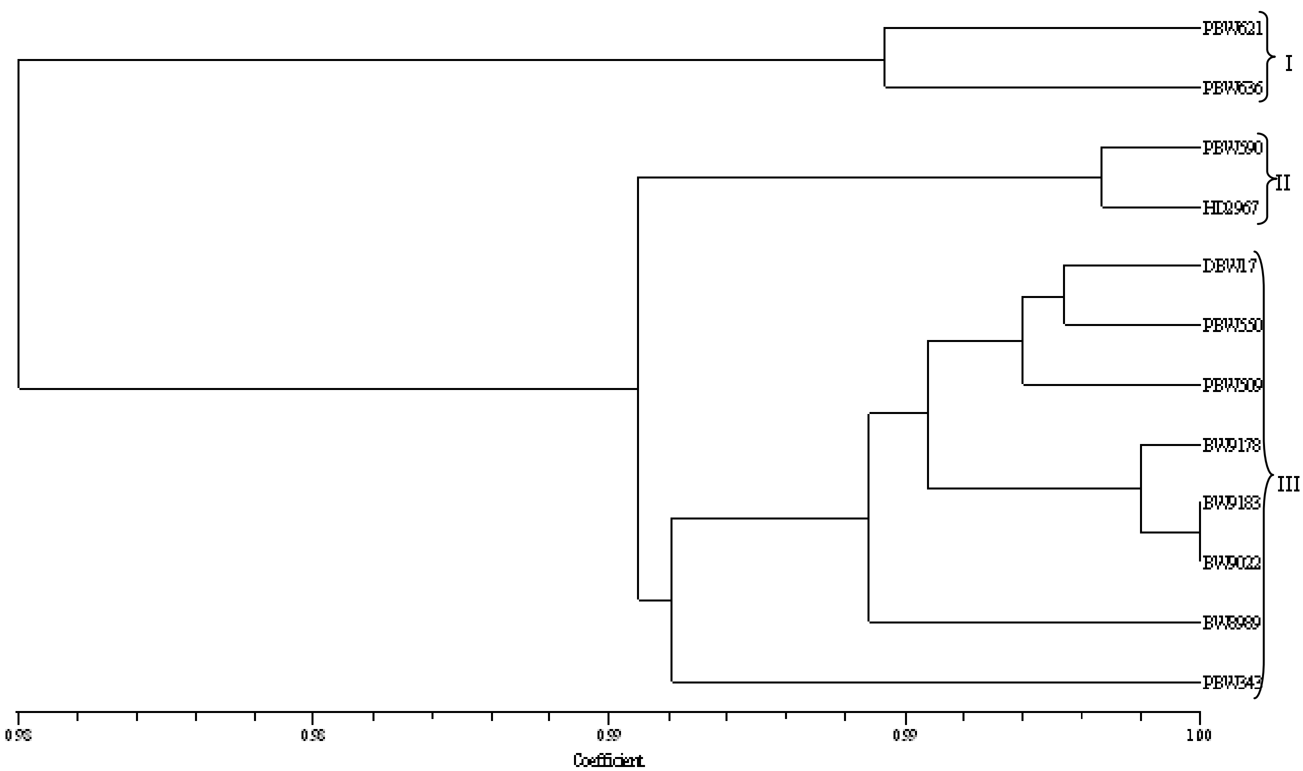

Figure 1. Cluster of twelve wheat genotypes by UPGMA clustering method for the years 2009-10 and 2010-2011.

9178, BW 9183, BW 8989, BW 9022 and PBW 343 were grouped together. PBW 621 and PBW 343 were at the opposite sides of the tree plot showing that they vary with respect to N use as also reflected from the data. Genotypes clustered together showed similar physiological behavior for N use. From cluster analysis of both years, it has been observed that PBW 621 and PBW 636 share similarity with respect to N use.

Conclusion

In conclusion, results of present study showed that PBW 621 and PBW 636 gave highest NUE and grain yield at sub optimal doses of N while widely grown cultivar PBW 343 and advanced breeding lines BW 8989 and BW 9022 showed a lower efficiency for N use. 120 kg/ha is the recommended N dose. However, considering environmental and economic issues, it has been observed that a decrease in N dose up to RDN-25% is tolerated by N efficient genotypes without marked loss in yield whereas further decrease from RDN-25% causes N starvation. It would be particularly interesting to further

Conflict of Interest

The authors have not declared any conflict of interest.

investigate the differential N responsiveness of contrasting genotypes in terms of complex regulatory network involved in NUE. These N efficient genotypes may be used as donor stocks in wheat breeding programs.

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