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Effect of Nitrogen Levels on Use Efficiencies and Yield of Wheat at Bharatpur, Chitwan, Nepal

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Abstract

Improper nitrogen management and declining soil fertility are major constraints of wheat production in Nepal. Limited information is available on optimum nitrogen levels and use efficiencies. Therefore, a field experiment was conducted on November 2018 at the Inner Terai to determine the effect of nitrogen on yield and improve the nitrogen use efficiency of wheat. Levels of five nitrogen, 0 kg ha^{-1} (Control), 60 kg ha^{-1},80 kg ha^{-1}, 100 kg ha^{-1} and 120 kg ha^{-1}, were laid out in randomized complete block design (RCBD) with four replicates. Observations on growth parameters such as plant height (cm), tiller m^{-2} and yield attributing characteristics such as thousand grain weight (g), spike length (cm), and grain spike^{-1}, were found to be highest at a nitrogen level of 120 kg ha^{-1}. Nitrogen at 120 kg ha^{-1} increases the grain yield, straw yield and harvest index. The grain nitrogen concentration at 120 kg ha^{-1} was statistically similar to that at 100 kg ha^{-1} and 80 kg ha^{-1} while nitrogen uptake was highest (114. 833 kg ha^{-1}) at 120 kg ha^{-1} and lowest in control. Agronomic use efficiency is highest at 100 kg ha^{-1} and lowest at 60 kg ha^{-1}. The apparent fertilizer N

recovery percentage was high (49.62%) at 120 kg ha^{-1}, which is statistically similar to 100 kg ha^{-1} (46.97%) and lowest (31.76%) at 60 kg ha^{-1}. However, observing agro physiological efficiency and the nitrogen harvest index did not show any significant difference among treatments. The application of nitrogen at 120 kg ha^{-1} was required to produce the preferable yield and the nitrogen use efficiency traits.

Introduction

Nitrogen is the major nutrient affecting the various physiological processes in the plants. It is indispensable in metabolic roles, such as the synthesis of proteins, nucleotides, nucleic acids, and chlorophyll. Nitrogen influences growth and development and promotes photosynthetic activities. Nitrogen is a limiting factor in crop production, and adequate and timely application is necessary for optimum crop production (Dobermann et al., 2003), while excess nitrogen leads to loss, which harms the environment, such as nitrate leaching, eutrophication, greenhouse gas emission, and soil acidification, and reduces crop yield (Huang et al., 2018). It is mobile in soil, and only 40-60% of applied is taken up by wheat, which is due to the poor synchronization between N application and crop demand (Erisman et al., 2018), and residual N is lost to the environment through leaching, volatilization or indirectly through the activity and competition of soil microorganisms (Guarda et al., 2004). The risk for loss of N increases when there are low utilization efficiencies that occur due to applied N exceeding the crop requirements (Ju et al., 2004). Effective and practical approaches are necessary to increase nitrogen uptake and use efficiency for a sustainable agricultural system and environment. (Reddy & Reddy, 1993).

Wheat is the leading cereal in the world, occupying 17% of the total cultivated land area of the world (CIMMYT, 2002). In Nepal, the national average yield of wheat is 2.3 t ha^{-1} (FAOSTAT, 2018.), while the experimental station yields of wheat are 5 t ha^{-1} (NARC, 2014). The gaps between attainable wheat yields and actual yields are quite large, which are, among many factors, mainly due to improper nitrogen management. It is necessary to improve the nitrogen use efficiencies of wheat to effectively capture and assimilate N to maximize yield per unit N applied (Sinebo et al., 2004). The application of nitrogen at an optimum rate has a positive impact on grain yield, spikes per plant, spike length, grains per spike, and biomass yield and reduces disease and pest infestation (Ghimire et al., 2019). Nitrogen doses vary with genotype and management system, but an average of 120 kg ha-1 is desirable for achieving the optimum yield without deteriorating soil health (Chaudhari et al., 2019). Soil and climatic factors play a crucial role in mobilizing nitrogen into a different form that has low accessibility to plants and thus decreases use efficiency (Timsina et al., 2001).

Nitrogen use efficiency depends upon the cultivars, and optimizing the level of nitrogen should be more responsive than not responsive; otherwise, application leads to toxicity, reduced yield, and environmental pollution (Guarda et al., 2004).

This study was carried out to evaluate the application rate of nitrogen on the yield attributing characteristics, nitrogen uptake, and use efficiencies of wheat.

Methods and Materials

Study area

The study was carried out from November 2018 to February 2019 in the Chitwan district of Nepal located at 27.670 N latitude and 84.430 E longitudes and 208 masl. The average annual temperature is 24°C with the maximum temperature of 28.5°C, minimum temperature of 16.8 °C and the average annual rainfall is 1993 mm. The soil type of the area experimental site is Dyschrochrept according to USDA taxonomy with sandy loam in texture. The soil was sampled from 0-20 cm depth and analyzed for physio-chemical properties (Table 1).

Table 1. Initial soil physiochemical characteristics of the study area.

Parameters	Result	Method
Texture	Sandy loam	Hydrometer (Bouyoucos,1962)
pH	6.7	Potentiometric (Jackson, 1959)
Organic matter	0.92%	Walkely and Black (Walkely & Black, 1934)
Total Nitrogen	0.07%	Kjeldahl (Bremner & Mulvaney, 1982)
Available Phosphorous	5.44 ppm	Olsen's (Olsen et al., 1954)
Available Potassium	0.14 ppm	Ammonium Acetate (Jackson, 1959)
Bulk density	1.132 g cm^{-3}	Core sampling technique (Keen, 1921)

Source: Regional soil testing laboratory, Sundarpur, Kanchanpur

Treatments and experimental design

Treatment consisted of five nitrogen levels, i.e., 0, 60, 80, 100, and 120 kg N ha^{-1} which was laid out in a randomized completely block design (RCBD) with four replications.

The gross plot size for planting was 2m x 3m = 6 m^2 with 8 rows spaced 25 cm apart. Four central rows with a net plot size of 3 m^2 are used for biometrical observation, and the distances between plots and blocks are 0.5 cm and 1 m, respectively. Potassium (Murate of Potash 60% K_2O) and phosphorous (Single superphosphate 16% P_2O_5) were applied as basal i.e., 25 and 50 kg ha^{-1}, respectively. Nitrogen (Urea, 46% N) was applied in 50% of samples at sowing, 25% at tillering and 25% at the booting stage as accordance with the treatments.

Data collection

The plant was randomly sampled from each plot, and data for plant height, grain per spike, and spike length were observed. A tiller area of 1 m^2 was marked inside the net plot, and data were collected. Similarly, grain and straw yields are collected from the net plot area.

Plants from the net plot area were harvested at 120 DAS, threshed, sun-dried, maintained at 12% moisture and weighed after threshing straw weight was taken immediately. Grain and straw samples were taken to the laboratory by grinding them to the fine particles for determination of nitrogen content by the Kjeldahl method (AACC, 1999). Total grain N uptake is determined by the total grain yield (kg ha-1) multiplied by the N content (%) in the grain. Total straw N uptake is determined by the nitrogen content in the straw multiplied by the total weight of the straw (kg ha-1). Total N uptake is the addition of total grain N uptake and total straw N uptake (Fageria et al, 2010). The nitrogen use efficiency traits are as follows:

Agronomic efficiency (kg^{-1})

$$AE = \frac{GF(Kg) - G0(Kg)}{\mathrm{NA(Kg)}}$$

Apparent fertilizer N recovery efficiency (%)

$$ARE\% = \frac{NUf(Kg) - NU0(Kg)}{\mathrm{NA(Kg)}} X100\%$$

Agrophysiological efficiency (kg kg^{-1})

$$APE = \frac{GF(Kg) - G0(Kg)}{NUf(kg) - NU0(Kg)}$$

where AE= Agronomic Efficiency kg^{-1}

Gf= Grain yield from Nfertilizedplots (60,80,100,120 $kgha^{-1}$)

G0=Grain yields from Unfertilized Plots.

NA= Nitrogen Applied.

NUf=Nitrogen uptake by fertilized plots.

NU0=Nitrogen uptake by unfertilized plots.

Nitrogen harvest index (%)

Estimated as the ratio of nitrogen uptake by grain and nitrogen uptake by grain plus straw yield (Fageria, 2014).

Data analysis

Analysis of variance (ANOVA) was performed by using R agricloae v 1.3, and mean comparison was performed using least significant difference (LSD) (Gomez & Gomez, 1984) at the 5% level of significance.

Results and Discussion

Effect of nitrogen doses on yield and yield attributes.

Plant height (cm)

Plant height (cm) was significantly influenced by the levels of nitrogen; the highest plant height (84.633 cm) was observed at 120 kg ha^{-1}, while the lowest (64.43 cm) was observed in the control. Nitrogen promotes cell division and differentiation, so the application of nitrogen helps to increase the height of wheat. A similar result is observed by (Singh, 2001) increasing the nitrogen application increases the plant height.

Table 2. Effect of nitrogen on growth and yield attributes

Nitrogen Levels	Plant height cm	Effective Tillersm^{-2}	Spike length cm	Grains Spikes^{-1}	TGW g	Grain Yield kg ha^{-1}	Straw yield kg ha^{-1}	Biological Yield kg ha^{-1}	Harvest index
0 kg ha^{-1}	68.43 c	226.76 d	7.76 b	26.60 b	24.96 c	2060.41e	3636.41 c	5696.83d	36.22 c
60 kg ha^{-1}	72.56 b	304.66 c	8.40 b	29.83 b	31.40 b	2698.07 d	3997.62b	6851.59c	39.37 b
80 kg ha^{-1}	81.33 a	338.03 b	9.30 a	37.23 a	34.33 b	3217.78 c	4153.51b	7215.40c	44.62 a
100 kg ha^{-1}	82.76 a	384.60 a	9.83 a	39.06 a	41.23 a	3637.61 b	4286.17ab	7923.78b	45.89 a
120 kg ha^{-1}	84.63 a	399.30 a	9.86 a	41.56 a	41.83 a	4133.22 a	4540.09 a	8673.32a	47.60 a
Mean	77.94	330.67	9.03	34.86	34.75	3149.42	4122.76	7272.17	42.74
CV%	8.49	7.66	9.95	6.87	5.17	5.26	6.61	6.65	7.75
SE	3.76	147	0.12	5.74	3.24	312.27	36205	70667	2.57
$LSD_{0.05}$	3.65	22.82	0.67	4.51	3.38	312.27	358.26	500.52	3.023

Note: Means followed by the same letter(s) within column do not differ significantly by DMRT at a 5% level of significance. SE=Standard error, LSD= Least significant difference, and CV=Coefficient of Variance.

Tillers (m^{-2})

Nitrogen levels had significant effects on Effective tillers per square meter. Tillers per square meter were highest (399.3 m^{-2}) at 120 kg ha^{-1}, and the lowest (226.766 m^{-2}) was observed in the control (226.766 m^{-2}). Optimizing nitrogen application increases the number of tillers in wheat (Bly & Woodard, 2003; Erisman et al., 2018). Nitrogen application increases the number of tillers and reduces tiller mortality (Rahman et al., 1970).

Spike length (cm)

Spike length (cm) is statistically similar over 120 kg ha^{-1}, 100 kg ha^{-1}, and 80 kg ha^{-1}; however, the lowest was observed in the control (7.76 cm), which is also statistically similar to 60 kg ha^{-1}. Ali et al. (2011) reported that spike length was significantly increased by increasing the nitrogen level over the control.

Thousand grain weight (g)

The highest Thousand-grain weight was found at 120 kg ha^{-1} (41.83 g), which is statistically at par with 100 kg ha^{-1} (41.23 g), and the lowest was found in the control (24.96 g). This result indicates that nitrogen is responsive to increasing the grain size of wheat. Arduini et al, (2006) reported that the application of N improves the grain size and grain N content. Zhang et al, (2017) observed influence of N fertilizer was highly significant on grain yield and TGW.

Grains spikes^{-1}

The highest observation of grains per spike was at 120 kg ha^{-1} (41.567), which is statistically similar to 100 kg ha^{-1} and 80 kg ha^{-1}, while the lowest was in the control (26.60). Generally, grain spike could be a genetic factor, but under the managed system, nitrogen has a significant effect on spike length. This observation is also confirmed by the result obtained by (Bielski et al, 2020).

Biological yield

Grain yield and straw yield were highest at 120 kg ha^{-1} (4133.27 kg ha^{-1}) (4540.097 kg ha^{-1}), followed by 100,80, and 60 kg ha^{-1}, and lowest in the control (2060.417 kg ha^{-1}) (3636.417 kg ha-1). Rahman et al., (1970) reported that gain and straw yield are highly significant over N application. Similarly, Belete et al., (2018) reported that the application of nitrogen is essential for obtaining optimum yield. Guarda et al., (2004) also reported the highest grain and straw yield at 120 kg ha^{-1} of nitrogen application. The biological yield was highest at 120 kg ha^{-1} (4673.32 kg ha^{-1}), and the lowest was observed in the control (5996.83 kg ha^{-1}).The application of nitrogen increases plant height, tillers, grain, and straw yield and dry matter production, which have a positive impact on biological yield. Ghobadi et al., (2010) reported that higher nitrogen increases the total dry matter production so that a large canopy increases the surface area of solar energy interception and production of assimilates.

Harvest index:

The harvest index was highest (47.60%) at 120 kg ha^{-1}, which was statistically significant at par with 100 kg ha^{-1} and 80 kg ha^{-1}, while it was lowest in the control (36.22%). The harvest index means that there is a translocation of assimilated from the source to the sink for the development of seeds. It is directly associated with the availability of nutrients for the production of dry matter and yield. The application of more nitrogen increases the biological yield up to a limit beyond that it causes toxicity (Ju et al., 2004).

Effect of nitrogen levels on grain and straw concentration and uptake.

Analysis of variance (ANOVA) shows that there is a significant difference in doses of nitrogen on grain nitrogen concentration. The grain nitrogen concentration is increasing with increasing doses. The highest grain nitrogen concentration was found in 120 kg ha-1 (2.21%), while the lowest (1.84%) was found in the control treatment. This is due to the optimum nitrogen availability increasing the N mobilization in grain at the filling stage. While increasing the nitrogen application from 60 to 120 kg ha-1, the grain nitrogen concentration was found to increase from 1.52% to 2.28% in wheat (Arduini et al., 2006). The nitrogen rate of 80,100, and 120 kg ha-1 is statistically similar to the grain nitrogen concentration. Application of nitrogen higher than the optimum requirement has little or no effect on grain nitrogen concentration and yield because it only prolongs the vegetative phase rather than the reproductive period with increasing biomass and partly filled grains (Thenabadu, 1972).

Table 3. Effect of nitrogen levels on nitrogen content and uptake.

Nitrogen Levels	Nitrogen content (%)		Nitrogen uptake kgha^{-1}		
	Grain	Straw	Grain	Straw	Total
0 kg ha^{-1}	1.84 c	0.36 e	37.96 e	13.32 e	51.28 e
60 kg ha^{-1}	1.97 b	0.41 d	53.17 d	17.16 d	70.33 d
80 kg ha^{-1}	2.13 a	0.47c	68.59 c	18.77 c	87.37 c
100 kg ha^{-1}	2.17 a	0.49 b	78.91 b	21.003 b	99.91 b
120 kg ha^{-1}	2.21 a	0.51 a	91.52 a	23.31 a	114.83 a
Mean	2.06	0.45	66.03	18.71	84.74
CV	5.53	6.61	7.33	6.24	5.78
SE	0.0027	0.00053	23.48	0.63	24.03
$LSD_{0.05}$	0.09	0.01	9.12	1.49	9.22

Note: Means followed by the same letter(s) within column do not differ significantly by DMRT at a 5% level of significance. SE=Standard error, LSD= Least significant difference, and CV=Coefficient of Variance.

The nitrogen content in the straw was significantly affected by the rate of nitrogen application; the highest concentration was observed in 120 kg ha^{-1} (0.51%), while the lowest (0.37%) was observed in the control (0 kg ha^{-1}). Increasing the nitrogen concentration with N application is due to the availability of sufficient nitrogen for vegetative growth and development with a profuse root system in wheat. A similar result is obtained when increasing the N application increases the N content in straw from 0 to 120 kgha-1 (Alemu et al., 2016).

The total N uptake (Grain &Straw) was highest at 120 kg ha^{-1} (91.55 kg ha-1+23.31 kg ha^{-1}), while the lowest was obtained at 0 kg ha-1 (37.96 kg ha^{-1}+13.32

kg ha^{-1}). There is a positive interaction between nitrogen applied and uptake that could be due to the highest N within the plant, which allows it to concentrate nitrogen as their yield increased. It has been reported that the highest N uptake of wheat resulted from the highest N applied (Motzo et al., 2004). Total n uptake represents the biomass yield concerning applied nitrogen. Thind et al., (2010) reported the highest biomass yield, and uptake was obtained from the optimum application of the nitrogen field. Effect of nitrogen doses on nitrogen use efficiency traits.

Agronomic efficiency

The highest agronomic efficiency is obtained from 100 kg ha^{-1} (18.42), which is statistically similar to 120 kg ha^{-1}, and the lowest is obtained from 60 kg ha^{-1}. However, the result shows that agronomic efficiency is in a decreasing trend while increasing the nitrogen rates. A similar result was also reported by Arduini et al., (2006), who described the trend of decreasing the AE while increasing the N fertilizer application.

Table 4. Effect of nitrogen doses on use efficiency.

Nitrogen levels	Agronomic efficiency kg kg^{-1}	Apparent fertilizer N recovery efficiency%	Agro physiological efficiency kg kg^{-1}	Nitrogen harvest index
0 kg ha^{-1}	-	-	-	79.64 a
60 kg ha^{-1}	13.62 b	31.76 c	33.25 a	78.95 a
80 kg ha^{-1}	14.46 b	43.45 b	32.65 a	78.46a
100 kg ha^{-1}	18.42 a	46.97 ab	32.42 a	77.52 a
120 kg ha^{-1}	16.94 ab	49.62 a	31.89 a	77.04 a
Mean	11.89	34.36	26.04	78.32
CV	14.18	9.08	4.36	6.97
SE	2.84	9.75	1.29	2.33
$LSD_{0.05}$	3.17	5.87	2.13	2.87

Means followed by the same letter(s) within column do not differ significantly by DMRTat a 5% level of significance. SE=Standard error, LSD= Least significant difference, and CV=Coefficient of Variance.

Agrophysiological use efficiency

There was no significant difference among the treatments against Agro physiological use efficiency, but the highest (33.25) was found in 60 kg ha^{-1}, while the lowest (31.89) was found in 120 kg ha^{-1}. The result obtained is too similar to the (Gauer et al., 1992). Concluded that APE depends upon genotypes, and the highest value is obtained at low N applied and vice versa. Tana et al., (2015) also reported that NUE in wheat is reduced by high N application.

Apparent fertilizer N recovery efficiency

A significant difference is observed among treatments against fertilizer N recovery efficiency. The highest N recovery is observed at 120 kg ha^{-1} (49.62), which is statistically similar to 100 kg ha^{-1} (46.97), and the lowest is observed at 60 kg ha^{-1} (33.25). The difference in NUE depends upon climate, genotypes, and nitrogen rates, and there will be a decline in apparent nitrogen recovery efficiency beyond 120 kg ha^{-1} (Gauer et al., 1992). Kidanu et al, (2000) reported that the recovery of N efficiency is high at 110 kg ha-1 compared to 60 and 85 kg ha^{-1} in wheat. Values ranging from 30-50% are generally considered a well-managed system for apparent fertilizer N recovery (Gauer et al., 1992).

Nitrogen harvest index

The nitrogen harvest index (NHI) seemed to be highest in the 0 kg ha-1 control (79.64%) and lowest in the 120 kg ha-1 control (77.04%), but all the treatments were statistically similar. The efficiency of N utilization, however, is affected by the N rate, genotype, and other environmental factors (Fageria, 2014). The present result is supported by the result obtained from (Kidanu et al., 2000) where the lowest NHI is obtained from 110 kg ha^{-1}, while the highest NHI is obtained from the control plot. The average value of NHI under the managed system is 73% (Sinebo et al., 2004). Treatments that produce the least aboveground biomass and grain yield have a high nitrogen harvest index (López-Bellido & Redondo, 2005)

Conclusion

The application of different nitrogen rates significantly affected the yield and yield of wheat. The application of nitrogen 120 kg ha^{-1} produces a high yield. However, observations of plant height, tiller m^{-2}, and spike length grain per spike of 120 kg ha^{-1} were statistically significant at par with 100 kg ha^{-1}. Similarly, the higher N content and uptake in grain and spike was observed at 120 kg ha^{-1} and lowest in the control. High agronomic use efficiency is obtained in 100 kg ha^{-1} in comparison to other, and apparent N recovery is obtained in 120 kg ha^{-1}. However, agro physiological use efficiency and the nitrogen harvest index were maximum in the control. Thus, the application of nitrogen at a range of 100-120 kg ha^{-1} is essential for obtaining the preferable yield. Nitrogen use efficiency traits are best obtained at the rate of 120 kg ha^{-1}.

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