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NITRATE LEACHING LOSSES REDUCTION AND OPTIMIZATION OF N-USE EFFICIENCY IN *Triticumaestivum* L. AND *Oryza sativa* L. CROP ROTATION FOR ENHANCING CROP PRODUCTIVITY

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Nitrogen management is a major challenge in the environment due toNO_3^-leaching and volatilization. To address this problem, a lysimeter experiment was conducted for rice-wheat with two lower N rates (15 and 30%) and three higher rates (15, 30 and 45%) than recommended rate (N100%). Higher leaching of NO_3^- was noted with N145% up to86.84 mg/leachate in rice while wheat crop showed maximum leaching 48.62 mg/leachate in same treatment. This revealed that during the rice-wheat rotation, NO_3^- leaching losses were the highest during rice growth than that of wheat. The uppermost rice-wheat grain yield was obtained with 15% higher N. The highest rice-wheat NUE was 31.26 g/g and 45.52 g/g with treatment N115%, respectively. It is concluded that treatment of N115%proved to be efficient than other treatments due to enhanced NUE and yield by reducing NO_3^-leaching losses. The findings of current study can be helpful to develop proper N fertilizer management strategies for rice-wheat rotation.

Keywords: Rice-wheat rotation, nitrogen management, NO_3^- leaching, nitrogen use efficiency, groundwater contamination.

INTRODUCTION

Application rates of N have an important role in agricultural crop production. Over the past four decades, the usage of N fertilizers has been increased to 7-fold (London *et al.,* 2005). The applications of N fertilizer to soil remain important facet of modern agriculture and ultimately are contributing to increase in crop yield about 30–50% (Vitousek *et al.,* 2009). The excessive N fertilization has resulted in increased soil N losses with decreased N use efficiency (NUE). The NUE in agricultural soils is 28–30%, while 45–50% of N is lost into the environment (London *et al.,* 2005; Lassaletta *et al.,* 2014; FAO, 2017).This lost fraction of N can cause serious environmental issues such as groundwater contamination and surface water eutrophication due to nitrate leaching (Rana *et al.,* 2018)and nutrient imbalances (Rana *et al.,* 2020a;Vitousek *et al.,* 2009). Therefore, enhancing N management practices and NUE is very crucial to meet the increasing global food demand and to reduce the impact of agricultural activities on the environment. Usually, loss of N is associated with rates of N application (Qiao *et al.,* 2012). In spite of the large input of N, the yield of crop is not consistently increasing (Xue *et al.,* 2014). Better NUE and crop production require increased plants N uptake and enhanced grain yield (Mueller *et al.,* 2012).

The NUE is important to meet dual requirements of reducing pollution and increasing productivity due to reducing N losses (Cassman *et al.,* 2003). Nitrogen use efficiency is used commonly to assess the N utilization situation in crops at farm scale and is defined as ratio of N input and output (Godinot *et al.,* 2014). Decreasing N loss and improving NUE are critical for a sustainable agriculture. But, the N excessive usage has led to decreased NUE and higher N losses through leaching, runoff, N_2O emission and ammonia volatilization to the ambient environment (Xue *et al.,* 2014).

Nitrate (NO_3^-) leaching in cropping systems is the key to N loss pathway and in hydrosphere is the principal NO_3^-source (Zhou *et al.,* 2012). Globally, losses of NO_3^-through leaching account for 19%of total N applied in the world (Lin *et al.,* 2001).In certain, leaching of N that may result inground water pollution, surface water eutrophication, and threaten to public health(Cui *et al.,* 2014). Higher concentration of NO_3^-may result in methemoglobinemia and stomach cancer in humans (Powlson *et al.,* 2008; Sutton *et al.,* 2011) which has provoked growing community concern in various developing and developed countries. As a result of this fact and the problems in the environment related to its use, NUE plays an essential role in reducing the environmental concerns and improving the sustainable production of crops (Asplund *et al.,* 2014).

Summer rice-winter wheat rotation is the utmost common pattern of farming in Asia which is receiving the huge synthetic N fertilizer inputs but have lower NUE (Ju *et al.*,2009; Liang *et al.*, 2011).In rice-wheat rotation a cycle of dry–wet favor the conditions for leaching of NO_3^-into shallow groundwater (Liu *et al.*, 2010).When the soil is reflooded before rice seedling transplantation in the following season after the wheat, the NO_3^-accumulation within the soil is susceptible to leach down. Soil contains both NO_3^- and NH_4^+forms of N that are available as mobile form in soil and plants utilize only 30–40% of applied N. Accordingly, more than 60% of the soil N is lost through leaching, denitrification and surface run-off (Raun and Johnson, 1999; Zhao *et al.*,2012). Numerous improved management practices could considerably increase NUE and reduce NO_3^- leaching such as reduction in N fertilizer application in soil (Peng *et al.*, 2011; Xue *et al.*, 2012), which is expected to regulate the NO_3^- buildup in soil profile through controlling the leaching of NO_3^-.

To cope with upcoming future demands of food for an increasing worldwide population, the sustainable intensification concept has been suggested (Rana *et al.*, 2020b; Ismael *et al.*, 2018). This broadly acknowledged idea suggests that greater production can be attained through reduced leaching of NO_3^-. It shows that the environmental sustainability and global food security challenges for coming decades can be achieved by carefully considering nutrient management. To-date, a few studies have focused on management of N fertilizer, NO_3^- leaching under altered levels of fertilizer and its application efficiency to rice-wheat rotation. However, there are still controversies in management of N fertilization to maximize rice and wheat yield, and it requires the improvement of NUE in rice-wheat rotation. Therefore, keeping above facts in view, this study was carried to see the effect of different N application rates on crop yield, N uptake, NUE, and nitrate leaching in rice-wheat cropping system.

MATERIALS AND METHODS

The study was carried out at Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan in lysimetersof1 m height and diameter of0.30 m. There were six treatments having three higher N rates (15, 30 and 45%) and two lower (15 and 30%) than recommended rate with three replications for each treatment. NPK fertilizer were applied @ 125, 75, 62 kg/ha and 120, 75, 62 kg/ha as urea, triple super phosphateandsulphate of potash, for rice and wheat, respectively. At sowing time, full dose of P and K was applied while N was applied in three splits. The chemical and physical characteristics of soil used for experiment were; pH, 8.04; EC, 2.52 dS m^{-1}; SAR, 9.71 (mmol $L^{-1})^{1/2}$; total Organic Carbon,0.47%; nitrogen,0.056%; Texture, sandy clay loam. From every lysimeter, composite samples of soil were collected after and before harvest of succeeding crops. Samples were air-dried, grounded and mixed thoroughly. The determination for SAR, pH_s, EC_e, soluble Ca^{2+}+Mg^{2+} (titration with versinate standard solution), HCO_3^- and CO_3^{2-} (titration with H_2SO_4 standard), Cl^- (titration with $AgNO_3$ standard), Na^+ (flame photometrically) and N were carried out by techniques defined by US Salinity Lab. Staff (1954). Nitrate-N was determined through chromotropic acid method (Sims and Jackson, 1971; Hadjidemetrious,1982). Sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) were calculated by following equations using Na^+, $Ca^{2+}$and Mg^{2+} concentrations in $mmol_c$ L^{-1}.

$$SAR = Na^+/[(Ca^{2+} + Mg^{2+})/2)]^{1/2}$$

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$

The leachates samples from wheat and rice were collected during respective crop duration. Leachate was collected form each replication. For wheat and rice leachate were collected at three and four different times, respectively. For each leachate sample, the volume was noted and analyzed through methods defined by US Salinity Lab. Staff (1954). During the whole period of crops growth, the canal water was used for irrigation. The characteristics of canal water used for irrigation were as follows; EC, 0.34 dS m^{-1}; TSS, 3.4 $mmol_c$ L^{-1}; CO_3^{2-}, absent; HCO_3^{2-}, 1.91 $mmol_c$ L^{-1}, Cl^-, 0.65 $mmol_c$ L^{-1}; SO_4^{2-}, 0.58 $mmol_c$ L^{-1}; Ca^{2+} +Mg^{2+}, 2.16 $mmol_c$ L^{-1}; Na^+, 0.74 $mmol_c$ L^{-1};SAR, 0.71 (mmol $L^{-1})^{1/2}$; RSC, Nil. Soil particle-size analysis was performed by the hydrometer method (Bouyoucos, 1962). A wire gauge was fixed at lysimeters bottom (62 cm long, 28cm internal dia.) with rubber bands with a thin glass wool layer and sand, this gauge was concealed to check the clay movement. Soil (42 kg) in each lysimeters was filled with special long neck designed funnel to avoid soil particles segregation. The analytical

Table 1. The treatments design.

Code	Rice Nitrogen (kg/ha)	Wheat Nitrogen (kg/ha)
C (Control, no N application)	0.00	0
N70 (30% less than recommended N rate)	87.50	84
N85 (15% less than recommended N rate)	106.25	102
N100 (Recommended N rate)	125.00	120
N115 (15% high than recommended N rate)	143.75	138
N130 (30% high than recommended N rate)	162.50	156
N145 (45% high than recommended N rate)	181.25	174

methods for water analysis were the same as used for the soil saturation extract analysis. Statistical analysis was performed through Statistix 8.1 software (Analytical Software, Tallahassee, FL, USA). All the results were expressed as mean ± standard error for three replicates. The data were analyzed statistically through using the ANOVA technique against the applied treatments. All-pairwise comparisons were carried out through least significant difference (LSD) test at $P \leq 0.05$ for mean variances of the data (Steel *et al.*, 1997).

RESULTS

Post-rice-wheat soil chemical properties: Before experiment, soil analysis revealed that soil EC_e, pH_s and SAR were in normal range as prescribed by US Salinity Lab. Staff, 1954 (Table 2) with sandy clay loamy texture. Highest decline in pH_s was 1.87% with N145 (45% higher N) treatment. Soil EC_e% decrease was statistically significant in accordance to N fertilizer application rate. EC_e maximum %decrease (17.06%) was noted with N145% and minimum (6.57%) with the N70% while it increased in control. Heavy irrigation to rice due to ecological demands boosted the soluble salts leaching that declined soil EC_e more efficiently in upper layer of soil. Extreme decline in the SAR was 26.36% with N145% followed by N130% (22.97%), N115%(20.70%), N100% (18.85%), N85% (17.61%), N70% (14.01%) and C (16.07%). After the harvesting of rice crop, soil pH_s, EC_e and SAR varied significantly by N-fertilizers.

In wheat, maximum pH was declined (1.61%) in N145% but remained non-significant with N115% and N130%. A little change in pH_s might be due to buffering of calcareous soils. Analysis indicated noteworthy alteration in salinity by N-fertilizers fluctuating rates (Table 3). EC_e maximum decrease (27.62%) was seen with N145%thatdiffered non-significantly from N130% while it increased with C (18.60%), N70% (9.97%) andN85% (1.04%) compared with initial EC_e of soil. Significant extreme SAR decrease was observed with N145% (29.04%) by the N varying rates while the least reduction was with C (6.44%).

Leachate volume and nitrate leaching of 132N soil: The N application rates affected the leachate volume in rice is presented in Fig. 1. Maximum leachate volume was 1222 mL in 1st leachate where applied nitrogen was30% lower which showed non-significant results with N145%, and minimum leachate of 1137 mL was with 15% lower N. In the 2nd leachate, highest volume of leachate was noted with N130%that remained statistically non-significant with N145%.In 3rdand4th leachate, highest leaching was recorded with N85% and N145%, respectively. In wheat, maximum volume of 763 mL was recoded in 1st leachate underN145% treatment that differed statistically from all other treatments while least volume (602 mL) was collected in the C treatment. The 2nd leachate was also highest where applied N was 45%

Table 2. Effect of N treatments on chemical properties of rice soil

Treatment	Soil pH		EC_e		SAR	
	Value	% change	dS m^{-1}	% change	(mmol L^{-1})$^{1/2}$	%change
C	8.19a	1.87	2.62a	3.97	8.15a	-16.07
N70	8.07d	0.37	2.35b	-6.75	8.35d	-14.01
N85	8.11c	0.87	2.30c	-8.73	8.00c	-17.61
N100	8.15b	1.37	2.23d	-11.51	7.88b	-18.85
N115	8.03e	-0.12d	2.220de	-12.70	7.70e	-20.70
N130	7.99f	-0.62	2.17e	-13.89	7.48f	-22.97
N145	7.89g	-1.87	2.09f	-17.06	7.15g	-26.36

The data are the mean of three replicates. Different small letters (a,b….) in each column are significantly different ($P \leq 0.05$) among different treatments.

Table 3. Effect of treatments on chemical properties of wheat soil

Treatment	Soil pH		EC_e		SAR	
	Value	% change	dS m^{-1}	% change	(mmol L^{-1})$^{1/2}$	% change
C	8.17a	0.99	3.41c	18.60	9.00a	-6.44
N70	8.08c	0.25	3.20e	9.97	8.62d	-10.49
N85	8.12b	0.37	2.92a	1.04	8.39c	-13.06
N100	8.15ab	0.49	2.86b	-3.38	7.89b	-18.07
N115	8.01d	-0.62	2.84b	-3.40	7.85e	-18.99
N130	7.99d	-0.87	2.29d	-23.41	6.99f	-27.79
N145	7.96d	-1.61	2.28d	-27.62	6.89g	-29.04

The data are the mean of three replicates. Different small letters (a,b….) in each column are significantly different ($P \leq 0.05$) among different treatments.

more than recommended level N and remained statistically non-significant with N130%.In control the lowest volume of 403 mL was collected. Likewise, results were seenin3rdleachate.

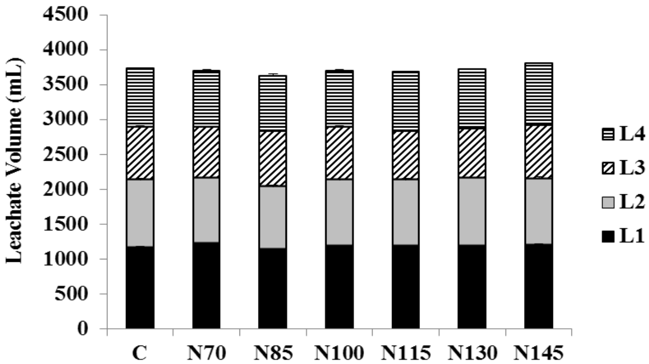

Figure 1. Volume of leachate collected from lysimeter during rice season. L1, L2, L3, L4 are indicating the three replications mean of leachate 1, leachate 2, leachate 3 and leachate 4, respectively. Vertical bars above mean indicate standard error of three replicates.

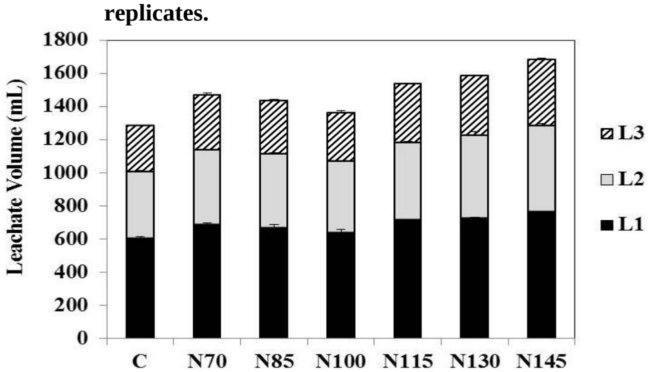

Figure 2. Volume of leachate collected from lysimeter during wheat season. L1, L2, L3, L4 are indicating the three replications mean of leachate 1, leachate 2, leachate 3 and leachate 4, respectively. Vertical bars above mean indicate standard error of three replicates.

The effects of different N application rates on NO_3^- leaching in rice and wheat are shown in Table 4 and 5. First leachate was taken8 days after transplantation of rice. In rice, during1st leachate, maximum NO_3^-(177.73 mg Leachate^{-1}) was noted with N145% that differed significantly with other treatments. In 2nd leachate, significant reduction in NO_3^-content was noted. Maximum NO_3^-concentration of 68.76 mg/leachate was with N applied @ 45% more than recommended rate. Then a decline was recorded in NO_3^-during the 3rd leachate. With N145%maximum NO_3^- concentration (50 mg leachate^{-1}) was noted. In wheat1st leachate, greatest NO_3^- (66.53 mg/leachate) was seen in N145% that differed significantly. A significant NO_3^-decrease was observed in 2ndleachate of wheat. Maximum NO_3^- concentration (48.33 mg leachate^{-1}) was noted when N applied @ 45% extra. Then again, there was a significant decline in NO_3^- in 3rd leachate of wheat. Maximum NO_3^- (31 mg/leachate) was noted with N145%.

Crop growth, paddy, grain yield and % N**:** Maximum height of rice plant was recorded with N145%treatment (135 cm) that differed significantly with all other treatments and minimum was seen with control treatment (Table 6). Increase in plant height followed the following order; N145% (135cm)>N130% (130 cm)>N115% (128 cm)>N100% (124 cm)>N85% (114cm)>N70% (104cm)>C (81cm). The results showed the similar trend for wheat as was in rice. The height of wheat plant significantly increased through increasing rate of N fertilizer (Table 6). Maximum plant height (106cm) was noted in N145% treatment. Plant height increased with the higher N as, C (69 cm), N70% (93 cm), N85% (97 cm), N100% (98 cm), N115% (100 cm), N130% (103 cm) and N145% (106 cm).

Maximum rice tillers were noted with N145%(17 tillers hill^{-1}) treatment that was statistically non-significant with N100%. While minimum tillers were recorded with C (3 tillers hill^{-1}). In wheat maximum (9 tillers plant^{-1}) numbers of tillers were recorded with N130%.These numbers of tillers were differed non-significantly among N100%, N115%, N130%and N145% while with C treatment remained significantly

Table 4. Effect of applied N-fertilizer on nitrate leaching during rice growing

Treatment	Nitrate leaching (Nitrate mg Leachate^{-1})					
	L1	**L2**	**L3**	**L4**	**Total**	**Relative %**
C	21.94g	11.09d	4.93e	13.59e	51.55	-
N70	44.85f	31.30c	8.37de	18.63de	103.15	100.09
N85	79.48e	37.30c	14.90cd	25.42cd	157.10	204.75
N100	98.99d	40.48c	17.51bc	33.71bc	190.71	269.91
N115	122.04c	56.12b	21.07bc	36.07b	235.30	356.45
N130	155.80b	58.00b	25.14b	40.75b	279.69	442.56
N145	177.73a	68.76a	49.85a	51.05a	347.39	573.88

The data are the mean of three replicates. L1, L2, L3, L4 are indicating the leachate 1, leachate 2, leachate 3 and leachate 4, respectively. Different small letters (a,b….) in each column are significantly different ($P\leq0.05$) among different treatments.

Table 5. Effect of applied N-fertilizer on nitrate leaching during wheat growing.

Treatment	Nitrate leaching				
	L1	L2	L3	Total	Relative %
C	7.68e	7.10d	3.58d	18.36	-
N70	17.89d	8.69d	9.97cd	36.55	99.07
N85	25.90cd	11.18d	12.60cd	49.68	170.58
N100	32.38c	21.49c	15.52bc	69.39	277.94
N115	44.27b	29.87bc	22.60ab	96.74	426.90
N130	51.78b	38.74ab	25.82ab	116.34	533.66
N145	66.53a	48.33a	31.02a	145.88	694.55

The data are the mean of three replicates. L1, L2, L3, L4 are indicating the leachate 1, leachate 2, leachate 3 and leachate 4, respectively. Different small letters (a,b….) in each column are significantly different ($P \leq 0.05$) among different treatments.

Table 6. Effect of application rate of nitrogen on different crop parameters.

Treatment	Rice			Wheat			Rice grain		Wheat grain		Total grain	
	Plant height (cm)	No. of tillers	Straw yield (g)	Plant height (cm)	No. of tillers	Straw yield (g)	g	Relative %	g	Relative %	g	Relative %
C	81f	3c	50c	69f	1c	25c	20d	-	16d	-	36	-
N70	104e	7b	89b	93e	3b	69b	36c	80	46c	187	82	127
N85	114d	9b	98b	97d	5b	75b	39c	95	50c	212	89	147
N100	124c	15a	128a	98cd	7a	89a	51b	155	60b	275	111	208
N115	128b	16a	131a	100c	8a	93a	65a	225	75a	368	140	288
N130	130b	16a	136a	103b	9a	95a	53b	165	63b	293	116	222
N145	135a	17a	142a	106a	7a	92a	52b	160	61b	281	113	213

The data are the mean of three replicates. Different small letters (a,b….) in each column are significantly different ($P \leq 0.05$) among different treatments.

Table 7. Effect of applied N-fertilizer on N concentration of shoot, grain in rice and wheat

Treatment	N % in Rice		N % in Wheat		N removal by crops	
	shoot	grain	shoot	grain	Total (mg/g)	Relative %
C	0.0053f	0.0027e	0.0061e	0.0038e	0.179	-
N70	0.0098e	0.0083d	0.0120d	0.0070de	0.371	107.26
N85	0.0091d	0.0074cd	0.0110cd	0.0060cd	0.335	98.32
N100	0.0078d	0.0058bc	0.0099c	0.0049c	0.284	58.65
N115	0.0117c	0.0094abc	0.0137b	0.0087b	0.435	143.01
N130	0.0130b	0.0106ab	0.0150ab	0.0100ab	0.486	171.50
N145	0.0148a	0.0117a	0.0163a	0.0113a	0.541	202.23

The data are the mean of three replicates. Different small letters (a,b….) in each column are significantly different ($P \leq 0.05$) among different treatments.

different both in rice and wheat. In wheat, yield decreased beyond N130% treatment.

The results indicated that rice and wheat straw yield increased significantly by enhancing N fertilizer rates (Table 6). Maximum yield was recorded with N145% but was statistically non-significant with N100%, N115%and N130% while, lowest straw yield was recorded with control (50 g pot^{-1}). In wheat, highest straw yield was noted in N130% up to 30%. The N application doses effect on paddy yield presented that paddy production significantly improved through enhancing N fertilizer dose up to N115% treatment(Table 6). Maximum rice grain yield (65g/pot) was with N115% while lowest was noted with control. Wheat grain production improved up toN115%treatment. Highest grain production (75 g pot^{-1}) was noted with N115%and differed significantly with C, N70%,N85%, N100%, N130%and N145% while it was minimum(16 g pot^{-1}) with control.

Nitrogen use efficiency (g/g) during crop growth**:** Generally, NUE significantly decreased with the increasing N rate. In rice and wheat NUE was maximum (31.26 g/g and 42.52 g/g, respectively) in N115%while was lowermost with N70% (rice) and N145%(wheat) (Table 7-8). NUE was not further improved due to increasing the levels of N. This study showed that NUE decreased with increasing N rate.

Table 8. Effect of N treatments on NUE (g g-1) of wheat and rice from normal soils.

Treatment	NUE of Rice ($g\ g^{-1}$)	NUE of Wheat ($g\ g^{-1}$)	NUE of Crops Total
N70	17.64c	35.13bc	52.77
N85	18.17c	32.73bc	50.90
N100	24.77b	35.87b	60.64
N115	31.26a	42.52a	73.78
N130	30.39bc	29.81cd	60.20
N145	17.75c	25.66d	43.41

The data are the mean of three replicates. Different small letters (a,b….) in each column are significantly different ($P \leq 0.05$) among different treatments.

DISCUSSION

The fertilizer usage is one of the most important sections of crop elements management. Nitrogen is being applied excessively to assure crop yield in cereal production systems. Our results showed that yield did not respond linearly to N fertilizer (Table 6). When N input went beyond the optimal N supply then the yield and environmental N losses (NO_3^- leaching) raised exponentially. Similar results were also reported by (Sutton *et al.,* 2011). Excessive application of N did not significantly increase rice-wheat grain yield. Howden *et al.*(2013) also have reported that higher potential for saving of N and improvement in efficiency exists for rice-wheat rotation. As our results indicated that at higher rates of N, the yield did not increase that could be due tolodging of crops and diseases. These results are in accordance to those of Islam *et al.*(2007). Higher number of tillers per plant and plant height in response to higher N rates could be due to higher activity of N related enzymes in both crops. Rana *et al.* (2018) and Imran *et al*. (2019ab) also reported the similar results. Generally, N efficiency decreased gradually with increasing N rates (Rana *et al.*,2018). In reverse to yield, our results showed a linear correlation amongst N application rates and NO_3^- leaching loss for rice-wheat cropping systems. Related trends between crop yield, rates of N applied and leaching losses of NO_3^- have been acknowledged in numerous studies (Perego *et al.,* 2012).

The results indicated that concentrations of NO_3^- in percolation water had a great temporal variability and positive correlation between applied N and loss of NO_3^-through leaching. Ju *et al.* (2009) and Robertson and Vitousek (2009) also have reported that NO_3^- leaching losses considerably increase when applications of N are higher than crop N demand. Our results are also in line with those of Perego *et al.* (2012) that NO_3^-substantial leaching losses allied with great N surplus. For all treatments, concentrations of NO_3^-got peak values in 1st leachate and then started to decline up to3rd leachate in wheat till the crops were harvested. In rice concentrations of NO_3^- after 3rd leachate showed increasing trend and it was maximum in N145% treatment. A pattern analogous to this was described by Zhou and Butterbach-Bahl (2014). Higher NO_3^-concentrations buildup in percolation water in the early growth stage of rice might have attributed to speed up the soil organic N mineralization or field flooding initially for rice. This NO_3^- concentrations buildup in percolation water contaminated the leachate that may cause eutrophication (Cao *et al.*, 2006; Fowler *et al.*, 2013) and the magnitude of NO_3^-leaching is reliant on two key factors: drainage volume and concentrations of N in percolation water (Liang *et al.,* 2011). During early growth stage of the rice, higher N amount accumulated in percolation water corresponded with a high drainage period that resulted in significantly higher N leaching. However, in the mid-late rice growth stage N leaching seemed to be lesser because of declined concentrations of N through a comparatively low permeability and reduction in the matric gradient potential. Zhou *et al.* (2009) also have reported the similar results. This specifies that the rice early growth stage is perceptibly crucial for alleviating N leaching. Similar to our findings, Zhao *et al.*(2012) also described that that greater NO_3^- leaching in highly permeable rice soils. This further shows that fertilizer N application in accordance to N requirements of crop is fundamental to decrease leaching losses of NO_3^- from the rice-wheat cropping systems. Therefore, decreasing N use excessive rates with better N requirements of crop is not a way only to lessening N, but also a key to elude NO_3^-considerable leaching losses.

Further analysis demonstrated that there was significant effect of N rates on NUE. Results revealed that NUE of rice-wheat rose up to a certain level of N addition and beyond this level negative relationship occurred between N application rate and NUE. These results are consistent with earlier observation who reported that higher level of N application reduces the NUE (He *et al.,* 2009). N-use efficiency was the maximum with N115%during both crop while was the lowest with N70% in rice and N130% in wheat. The higher rates of N application (>N115%) decreased NUE, increased NO_3^--N losses due to greater surplus supply of N than crops demand (Cameron *et al.,* 2013; Galloway *et al.*,2013). It is proposed that the greater and improved NUE could be attained either by reducing N application rate in the N overuse areas. In this study, the N optimum application rate (N115%)attained both higher grain yield and NUE. In treatment N115%, the NUE was good and there was minimal risk of leachate pollution. The basic of improved nitrogen management for decreasing NO_3^- loss is associated to either improving crop NUE through decreasing N surplus.

In our research, in the rice–wheat rotation, the N115% treatment had greater yield, plant N uptake and NUE than other treatments that made a better balance between crop demand and N supply. Zhao *et al.* (2015) also described the similar findings in their experiments that optimum level of N fertilization will ultimately lead toward the higher crop yield and low N losses. Thus, we suggest that to evaluate the nutrient management practices effects in the rice-wheat rotation on yield; a complete rotation system should be assessed. During last decade, with the N in creasing rate, grain yield of rice-wheat crops has got a plateau as the unnecessary N application led to decline in NUE. The fertilizer management practice in our research considerably enhanced crop yield and NUE and also gave deep insight for managing the NO_3^- leaching losses to reduce the N use cost and environmental risks in the rice–wheat rotation.

***Conclusion*:** The present study demonstrated that maximumNO_3^- leaching was observed with N145% treatment. While N115% proved the best regarding the improvement in crops yield and NUE. The appropriate N fertilizer in season managing strategy could match crop N necessity with N supply which is effective way to maximize the grain yield, higher NUE and reduce N loss. It was concluded that N application rates above N115% would not considerably improve the yield, but lead to greater NO_3^- leaching. NUE decline in rice was ascribed to submerged conditions that assisted leaching of NO_3^-.Avoiding excess water leaching by matching nitrogen use to crop N requirement is the main key to increase NUE, reduce NO_3^- leaching, and retain crop yield. These results indicate that N115% treatment might be the best for optimizing the yield and nitrogen losses as well as environmental friendly.

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