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Effect of inline drip fertigation on inorganic forms of soil nitrogen in hitherto rainfed rice based cropping systems of Eastern India

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Abstract
The present investigation was carried out in an on-going fertigation experiment involving rainfed rice based cropping systems initiated in June, 2014 at the farm of Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India. This study was conducted during the sixth cycle of the system (*Kharif,* 2019). The sample for analysis was taken from two depths of soil (0-15cm and 15-30cm). Split plot design was taken having 12 treatments which replicates thrice. Top soil as well as subsoil nitrogen availability was found more to be a function of the fertilizer addition and crop uptake rather than biological nitrogen fixation by legumes. The highest fertigation regime resulted in significantly higher nitrogen availability in the surface soil at the time of rice crop establishment but this did not persist till the harvest of the rice crop, when significantly higher nitrogen availability in the surface soil was found in the lowest fertigation regime. After rice harvest, ammonical and nitrate nitrogen content was also found to significantly higher in the lowest fertigation regime in the top soil and in the highest fertigation regime in the sub soil. Top soil nitrogen availability seems to directly influence the nitrogen uptake by rice from the sub soil which has significance for the system sustainability.

Keywords: Ammonical nitrogen, nitrate nitrogen, rice-based cropping systems

Introduction
Nitrate and ammonical nitrogen are two important forms of nitrogen taken up by plants and approximately 70% of the total ions are absorbed by plants in these two inorganic forms of nitrogen (Caicedo *et al.*, 2000) [3]. High inorganic nitrogen in soil is conductive to crop uptake (Liu *et al.*, 2003). Application of nitrogenous fertilizers may lead to increased nitrate nitrogen accumulation in the lower soil layers (Fan *et al.*, 2003) [4]. There is a rapid transformation of ammoniacal nitrogen derived from soil to nitrate nitrogen through nitrification (Smiciklas *et al.*, 1992) [11] resulting in higher nitrate content and lower ammoniacal content in the soil (Velbel *et al.*, 1997) [13], with ammonium nitrogen and nitrate nitrogen providing the major sources of inorganic nitrogen for plants (Nelson *et al.*, 1974). Nitrogen applied through fertilizers can be lost through different pathways such as denitrification, volatilization and runoff (Kirda *et al.*, 2001) [6]. This is because all of the fertilizer applied nitrogen is not taken up by the plants immediately after application. Most of the fertilizer nitrogen is first of all immobilized by the soil microorganisms. Mineralization of the soil microbial biomass then makes nitrogen again available for plants. Mineral nitrogen in nitrate and ammoniacal forms are subject to leaching and volatilization losses respectively. Fertigation can potentially reduce these losses of nitrogen in comparison to broadcasted or drilled fertilizers. The ammoniacal, nitrate and mineral nitrogen content of the soil solution gradually decrease with increasing rice growth and the microbial biomass nitrogen increases by combined application of organic materials and chemical fertilizers (Yu *et al.*, 2020) [15]. The content of various inorganic forms of nitrogen changes with different management practices and cropping systems (Kumar & Mishra, 2016). Thus various cropping systems under fertigation may exhibit varying levels of inorganic forms of nitrogen. This paper intends to document the availability of various forms of inorganic nitrogen following six cycles hitherto rainfed rice based cropping systems.

Materials and Methods
Available Nitrogen was estimated using alkaline permanganate method (Subbiah and Asija,

1956). Ammoniacal and nitrate nitrogen were measured by potassium chloride method (Kenney and Bremner, 1966) [5]. Sample was shaken for 1 hour with 2M KCl and the extract was steam distilled with magnesium oxide and Devardas alloy. The amount of liberated NH_3 was absorbed in boric acid and titrated with 0.02 N H_2SO_4.

An experiment on fertigation in zero till direct seeded rice based cropping systems involving zero till direct seeded durum wheat (C_1), barley (C_2), chickpea (C_3) and lentil (C_4) laid out in a split plot design as sub plot and three levels of fertigation as main plots which includes W_1- N @ 20 kg ha^{-1} in rice through fertigation followed by 200 mm irrigation in post rice crops, W_2-N @ 40 kg ha^{-1} in rice through fertigation followed by 300 mm irrigation in post rice crops W_3-N @ 60 kg ha^{-1} in rice through fertigation followed by 400 mm irrigation in post rice crops with three replications was initiated in the *Kharif* season of 2014. The size of each sub-plot was 4.0 m x 4.2 m and was separated from the surrounding plots by a bund measuring 0.5 m in width. The fertigation treatments were modified as W_1- N @ 40 kg ha^{-1} in rice through fertigation followed by 200 mm irrigation in post rice crops, W_2-N @ 60 kg ha^{-1} in rice through fertigation followed by 300 mm irrigation in post rice crops, and W_3- N @ 80 kg ha^{-1} in rice through fertigation followed by 400 mm irrigation in post rice crops. The experimental field and bunds were subjected to spray of glyphosate @ 1 kg a.i. ha^{-1} + 2,4-D @ 1 kg a.i. ha^{-1} for clearing the standing weeds after the harvest of *rabi* season crops in 2018-19. The seeds of rice variety Sahbhagi Dhan were drilled in rows 30 cm apart @ 30 kg ha^{-1} along with MOP and SSP for application of 20 kg K_2O ha^{-1} and 40 kg $P_2O_5 ha^{-1}$respectively on 25thJune 2019. Nitrogen was applied as urea @ 100, 75 and 50 per cent of the rainfed RDF of 80 kg N ha^{-1} in the respective treatments (i.e. 80, 60 and 40 $kgha^{-1}$ respectively). The N application rates in rice since 2014 had been lower at 60, 40 & 20 $kgha^{-1}$ since 2014. One third of the respective dose of nitrogen was incorporated along with the P and K fertilizers before sowing of seeds in the rows. The remaining amount was applied in two split doses of nitrogen through fertigation at the panicle initiation and active tillering stages respectively. All visible weed plants were manually uprooted as and when observed during the crop growing season. During the crop growth period, Bispyribac Sodium was sprayed one time at the rate of 100 ml in 100 litre of water to remove weeds. Every year during the rabi season after harvesting of the wet season rice crop, the field was subjected to a spray of Glyphosate @ 1 kg a.i. ha^{-1} + 2,4-D @ 1 kg a.i. ha^{-1} for clearing the standing weeds in the experimental field and bunds. The seeds of various post rice crops are then drilled along with the recommended doses of fertilizers in rows by line sowing in sub plots without any primary tillage. The respective doses of fertilizers in terms of nitrogen, phosphate and potash are given in Table 1. All weeds were uprooted manually as and when observed in the field.

Results

Soil available Nitrogen (N)

Data pertaining to the effect of fertigation and rice based cropping systems on available nitrogen of surface (0-15 cm) and subsurface (15-30 cm) soil before sowing and after harvest of rice crop is presented in Table 1. Fertigation regimes and cropping systems had a significant effect on available nitrogen in surface soil. The highest available nitrogen was found in higher fertigation regimes followed by medium and lower fertigation regimes. For cropping system highest value was recorded in rice-barley cropping system followed by rice- lentil, rice-durum wheat and rice-chickpea cropping system but found to be non-significant in subsurface soil before rice crop establishment (Table 1). Fertigation regimes had a significant effect on surface and subsurface available nitrogen after harvest of rice crop. In surface soil highest value of available nitrogen was observed in lower fertigation regime followed by medium and higher fertigation level but in subsurface soil it follows the trend $W_3>W_2>W_1$. Cropping system had significant effect on available nitrogen in subsurface soil after harvest of crop. The highest available nitrogen was recorded in the rice-durum wheat cropping system and the lowest was observed in the rice-lentil cropping system. Interaction effect was found significant in the subsurface soil and the available nitrogen was highest observed in the W_3 and rice-barley cropping system. There was no significant effect of cropping systems on surface soil after harvest of crop (Table1).

Effect of different fertigation regimes and rice-based cropping systems on inorganic forms of soil nitrogen

Ammonical-nitrogen: The data regarding the effect of fertigation regimes and rice based cropping systems on ammoniacal nitrogen content at both soil depths 0-15 cm and 15-30 cm before sowing of rice crop and after harvesting of rice has been presented in Table 3. Before rice crop establishment, the fertigation regimes had no significant effect on ammoniacal-nitrogen content in surface and subsurface soil but rice chickpea cropping system exhibited significantly higher ammoniacal nitrogen content in the top soil as compared to rice durum wheat cropping system. In the sub-soil, various cropping systems were exhibited statistically similar values of ammoniacal-nitrogen. After harvest of the rice crop, ammoniacal nitrogen content was found to be significantly higher in the lowest fertigation regime in comparison to the highest fertigation regime in the top soil and vice versa in the sub soil. Ammoniacal nitrogen content after harvest of the rice crop was found to be significantly higher in rice chickpea cropping system in comparison to other cropping systems in the top soil and significantly higher than that in the rice-durum wheat cropping system but at par with that of the other two cropping systems in the subsoil.

Nitrate-nitrogen

The data regarding the effect of fertigation regimes and rice based cropping systems on nitrate nitrogen content at both soil depths 0-15 cm and 15-30 cm before sowing of rice crop and after harvesting of rice has been presented in Table 4. Before rice crop establishment, the fertigation regimes had no significant effect on nitrate-nitrogen content in surface and subsurface soil but rice chickpea cropping system exhibited significantly higher nitrate nitrogen content in the top soil as compared to rice durum wheat cropping system. In the sub-soil, various cropping systems were exhibited statistically similar values of nitrate- nitrogen. After harvest of the rice crop, nitrate nitrogen content was found to be significantly higher in the lowest fertigation regime in comparison to the highest fertigation regime in the top soil and vice versa in the sub soil. Nitrate nitrogen content after harvest of the rice crop was found to be significantly higher in rice chickpea cropping system in comparison to other cropping systems in the top soil and significantly higher than that in the rice-durum wheat cropping system.

Discussion

Soil available nitrogen (N)

Continuous N application and water improves the N availability in the soil (Wang *et al.* 2016). In this study, available N content was found higher in the increased fertigation regimes than the lowest fertigation regime. It indicates that application of higher N dose and water continuously for last 6 years results into improved N availability in the soil even though a large extent of added N has been uptake by the crop for yield response and lost due to volatilization, leaching and denitrification. Soil N content was decreased after harvest of the crop even though it was applied to the crop mainly cereals based cropping systems. This was probably due to higher N uptake by the rice crop for yield response showing its negative balance compared to before crop establishment and the fact that cereal crops have a fibrous root system which absorbs more nutrients from top soil than subsurface soil. In subsurface soil, available N content was higher than surface soil for both time of sampling. This was due to leaching of N from the top soil to sub-surface soil which got accumulated and resulted into improved soil N content. Similar results were reported by Batjes (1996) [1] and Benbi & Senapati (2010) [2]. They reported that decreased in soil available N with depth was due to decline in root density, SOC content and microbial activity. Among all cropping systems, rice- cereal cropping systems (i.e. barley and durum wheat) had significantly higher soil available N content compared with rice-legume based cropping systems. This was due to the fact that this crop had utilized lesser amount of N for biomass production. Similar results were reported by (Rochester *et al.* 2001).

Ammonical-nitrogen

Ammonical-N was found highest in the rice-chickpea cropping system. This is due to leguminous crop have capacity to fix nitrogen in soil which increase the amount of Ammonical-N in the soil. Fertigation regimes as well as cropping systems both showed a significant impact on ammoniacal form in surface as well as subsurface soil. Across all fertigation regimes, Ammoniacal-N was significantly lower in higher fertigation regimes, which might be due to more Ammoniacal-N was utilized by rice crop with initial greater supply of nitrogen. Application of N fertilizer and nitrogen fixing capacity of leguminous crop increases the ammoniacal form in soil (Kumar *et al.* 2010). Ammoniacal-N was initially more in the soil than after harvest but after harvest of crop it decreased because it was taken up by plants. A decreasing trend was found with increasing depth. Similar result was reported by (Yana *et al.* 2018) [14].

Nitrate-Nitrogen: Similar to Ammonical-N, nitrate-N was highest in the rice-chickpea cropping system than other cropping systems. This is due to leguminous crop have capacity to fix nitrogen in soil (Duzdemir *et al.* 2009). Fertigation regimes as well as cropping system both have significant impact on nitrate form in surface as well as subsurface soil. A decreasing trend was found with increasing depth. Nitrate-N was initially high in the soil but after harvest of crop it decreased because it was taken up by plants. Similar result was reported by (Yana *et al.* 2018) [14].

Table 1: The varieties and fertilizer dose for various post rice crops being used in the experiment

Season	Crop	Variety	Fertiliser dose ($N:P_2O_5:K_2O$ kg ha^{-1})
Kharif	Rice	Sahbhagi Dhan	80:40:20
Rabi	Durum wheat	HI-8627	120:60:40
	Barley	Local	80:60:40
	Chickpea	BG-372	50:40:60
	Lentil	Arun	18:46:0

Table 2: Effect of fertigation and cropping systems on available nitrogen (kg ha^{-1}) after 6th Rice crop during 2019 at BAC farm, Sabour

Treatments	0-15cm								15-30cm							
	W1		W2		W3		Mean		W1		W2		W3		Mean	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Rice-Durum wheat (C_1)	180.3	152.0	187.3	138.4	195.4	131.0	187.7	140.5	144.8	102.8	136.4	104.8	149.0	105.4	143.4	104.3
Rice-Barley (C_2)	191.4	145.0	191.5	132.6	227.8	138.9	205.9	138.8	132.2	93.9	140.6	90.4	132.2	116.5	135.0	100.3
Rice-Chickpea (C_3)	155.2	156.5	184.4	141.9	213.0	134.8	182.3	144.4	132.2	89.9	128.0	100.6	136.4	111.4	132.2	100.6
Rice-Lentil (C_4)	174.2	145.3	184.8	145.6	221.0	137.6	192.2	142.8	140.6	94.2	140.6	95.5	144.8	101.2	142.0	97.0
Mean	175.3	149.7	186.4	139.6	214.3	135.6			137.4	95.2	136.4	97.8	140.6	108.6		
LSD(0.05) F:C:F X C (before sowing)	23.98:15:98:NS								NS:NS:NS							
LSD(0.05) F:C:F X C (after harvesting)	11.52:NS:NS								10.49:4.46:10.55							

Note: W_1= N @ 40 kg ha^{-1} in rice through fertigation followed by 200 mm irrigation through inline drip system in post-rice crops; W_2= N @ 60 kg ha^{-1} in rice through fertigation followed by 300 mm irrigation through inline drip system in post-rice crops; W_3 = N @ 80 kg ha^{-1} in rice through fertigation followed by 400 mm irrigation through inline drip system in post-rice crops.

Table 3: Effect of fertigation regimes and cropping systems on ammonical-nitrogen in soil (kg ha^{-1}) during 2019 at BAC farm, Sabour

Treatments	0-15cm								15-30cm							
	W1		W2		W3		Mean		W1		W2		W3		Mean	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Rice-Durum wheat (C_1)	83.14	77.45	79.58	59.68	103.26	62.35	88.66	66.50	46.04	44.27	57.19	42.38	44.07	42.04	49.10	44.66
Rice-Barley (C_2)	84.70	74.07	96.67	70.22	101.42	63.53	94.36	69.27	46.91	45.10	56.17	50.67	53.70	51.63	52.26	49.14
Rice-Chickpea (C_3)	97.14	84.03	102.20	76.65	98.71	69.60	99.35	75.65	51.97	46.64	54.67	52.56	56.60	56.76	54.41	51.99
Rice-Lentil (C_4)	87.66	70.64	95.52	71.64	94.19	65.75	92.46	69.34	48.55	46.68	52.16	46.82	52.90	50.86	51.20	48.12
Mean	88.16	76.55	93.57	69.55	99.40	65.31			48.37	45.67	55.05	49.43	51.82	50.32		
LSD(0.05) F:C:F X C (before sowing)	NS:7.27:NS								NS:NS:NS							
LSD(0.05) F:C:F X C (after harvesting)	10.15:9.14:NS								2.94:4.96:NS							

Note: W_1= N @ 40 kg ha^{-1} in rice through fertigation followed by 200 mm irrigation through inline drip system in post-rice crops; W_2= N @ 60 kg ha^{-1} in rice through fertigation followed by 300 mm irrigation through inline drip system in post-rice crops; W_3 = N @ 80 kg ha^{-1} in rice through fertigation followed by 400 mm irrigation through inline drip system in post-rice crops.

Table 4: Effect of fertigation regimes and cropping systems on nitrate-nitrogen (kg ha^{-1}) during 2019 at BAC farm, Sabour

Treatments	0-15cm								15-30cm							
	W1		W2		W3		Mean		W1		W2		W3		Mean	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Rice-Durum wheat (C_1)	50.67	57.45	47.64	39.68	65.44	42.35	54.58	46.50	31.04	23.22	42.19	22.91	29.07	39.68	34.10	28.60
Rice-Barley (C_2)	52.00	54.07	62.42	50.22	66.21	43.53	60.21	49.27	31.91	24.10	41.17	32.12	38.70	36.77	37.26	31.00
Rice-Chickpea (C_3)	62.57	64.03	66.87	56.65	63.91	49.60	64.45	56.76	36.97	31.55	39.67	40.00	41.60	40.64	39.41	37.39
Rice-Lentil (C_4)	54.51	50.64	61.87	51.64	60.06	45.75	58.59	49.34	33.55	25.76	37.16	33.29	37.90	33.82	36.20	30.96
Mean	54.91	56.55	59.53	49.55	63.90	45.31			33.37	26.15	40.05	32.08	36.82	37.73		
LSD(0.05) F:C:F X C (before sowing)	NS:6.33:NS								NS:NS:NS							
LSD(0.05) F:C:F X C (after harvesting)	7.09:5.64:NS								8.35:5.56:NS							

Note: W_1= N @ 40 kg ha^{-1} in rice through fertigation followed by 200 mm irrigation through inline drip system in post-rice crops; W_2= N @ 60 kg ha^{-1} in rice through fertigation followed by 300 mm irrigation through inline drip system in post-rice crops; W_3 = N @ 80 kg ha^{-1} in rice through fertigation followed by 400 mm irrigation through inline drip system in post-rice crops.

Conclusion

Surface soil available nitrogen was significantly higher in the highest fertigation regime and under rice-barley system in comparison to other fertigation regimes and cropping systems before establishment of the rice crop, but this higher nitrogen availability did not persist till after rice harvest when available nitrogen in the surface soil was found to be higher in lower fertigation regime but in the sub surface soil was found to be significantly lower in the lowest fertigation regime. Subsurface soil available nitrogen was significantly higher in rice - durum wheat cropping system in comparison to other treatments. Nitrate nitrogen in the top soil as well as the sub soil before rice crop establishment was found to be statistically similar across various fertigation regimes. But after rice harvest, nitrate nitrogen content was found to significantly higher in the highest fertigation regime in the top soil and in the lowest fertigation regime in the sub soil. Before rice establishment, ammonical and nitrate nitrogen was significantly higher in rice-chickpea cropping system in the surface soil. But after harvest of crop, higher values of ammonical and nitrate nitrogen were obtained in lower fertigation regimes and in rice-chickpea cropping system.

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