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Impact of Water Management on Nitrogen Dynamic in Low Land Paddy Soil

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Abstract: Lowland paddy cultivation requires relatively higher amount of water. The nitrogen dynamics in lowland paddy can be affected by various factors such as climatic and agronomic individually or in combination. In order to understand the effect of these factors and to reduce the complexity of the field conditions, a controlled experiment was carried out. An experiment was designed to identify the impact of alternative wetting and drying (AWD) cycles with different drying periods on the variation of NO_3^- -N and NH_4^+-N using a physical model (Lysimeter) together with simulations using Hydrus-1D. The experiment was conducted with following treatment combinations for 98 days. The data were analyzed using complete randomized design with three replicates. 4 days dry spell (D_4), 12 days dry spell (D_{12}), 20 days dry spell (D_{20}) and 4 days dry spell with plant (D_{4p}) were arranged using complete randomized design with three replicate to clarified the effect of length of dry spells and the plant on nitrogen. NH_4^+-N showed a decreasing trend over the study period in all treatments. On the other hand, NO_3^--N increased in leachate with time. The NO_3^--N loss in the leachate was higher than NH_4^+-N regardless of the length of the AWD cycles. With the presence of paddy, the nitrogen retention and leaching loss was low. Therefore, the irrigation interval would have to be decided along with the rainfall variability to reduce the nitrogen loss in paddy field. The Hydrus-1D could be used to simulate the impact of AWD on NO_3^--N loss. The measured and the simulated concentration of NO_3^--N correlated with R^2 values of 0.89, 0.79, 0.74 and 0.69 for D_4, D_{12}, D_{20} and D_{4p}, respectively. The NO_3^--N loss in the leachate was higher than NH_4^+-N regardless of the length of the AWD cycles. The length of the dry spells up to 12 days did not show significant variation in nitrogen loss in this study compared to 20 days dry spell. Therefore, the irrigation interval has to be decided along with the rainfall variability to reduce the nitrogen loss in paddy field.

Keywords: Alternative Wetting and Drying, Hydrus -1D, Nitrogen loss, Paddy

Introduction

Lowland paddy cultivation requires relatively higher amount of water. The ponded water plays a central role in weed control, soil biomass accumulation and decomposition, nutrient availability, crop growth and the yield. However, under minor irrigation systems, maintaining a continuous flooded condition is difficult due to high rainfall variability and lack of enough water in the tanks throughout the growing season. Alternate wetting

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and drying (AWD) is therefore a common phenomenon in paddy fields.

The extension of a dry spell in an AWD cycle will cause irregular and extreme water stresses for soil organism and plants. This affects nutrient availability, plant productivity, biogeochemical processes, gaseous and leaching losses and carbon and nitrogen pools in soils (Borken and Matzner, 2008). The drying and rewetting impose a significant stress on the microbial community of soil. While wetting events are common in most environments, the short and long-term effects of soil drying on microbial processes have not been well understood. Therefore, it is important to understand the consequences of varying dry spells on the soil microbial community and other soils processes.

Nitrogen plays an important role in crops grown under supplementary irrigation (Tavakkoli and Oweis, 2004). Nitrogen accumulation and leaching in soil profiles with different irrigation schedules and rate of fertilizer application have been reported (Wei *et al*., 2010; Sepaskhah, 2012). Nitrogen losses in paddy fields under AWD cycle can be extremely large compared to continuous flooding conditions because of the difference in nitrogen transformations between anaerobic and aerobic environments (Tan *et al.,* 2015).

Nitrate-N (NO_3^--N) formed by nitrification of ammonium nitrogen (NH_4^+-N) during drying regimes can be quickly lost by denitrification in the following wetting regimes (Buresh *et al*., 2008; Dandeniya and Thies, 2010). The formation of aerobic and anaerobic condition depends on the number dry days in the AWD cycles. Short period may not create effective aerobic conditions. This also may depend on the infiltration and drainage characteristics of the soil.

Therefore, owing to these different soil processes, environmental conditions and management, the amount of nitrogen can vary with plant type, growth stage, fertilizer, time and the soil depth. Objective of this study was to identify and assess the impacts of AWD cycles with different drying period on the variation of NO_3^--N and NH_4^+-N. For achieving this objective under similar conditions to lowland paddy, a physical model (Lysimeter) and Hydrus-1D model was used.

Materials and Methods

Preparation of Lysimeter and treatment combinations

Rectangular plastic containers were used to prepare Lysimeters for the experiments. Twelve containers each having 54 cm length, 36 cm width and 30 cm depth with the surface area of 0.194 m^2 were used to simulate the field condition. A drainage system with perforated PVC pipe was placed at the bottom of the Lysimeter. The pipes were connected to a common pipe for drain water to a common outlet. The metal aggregates with the diameter of 1 - 2 cm were placed up to 3 cm from the bottom to cover drainage pipes to facilitate free water flow. Then a plastic mesh was placed on top of the aggregates to prevent soil movement. Soil collected from the command area of Bayawa minor irrigation system was used to fill the Lysimeters. Sieved soil (< 2 mm) was filled up to 15 cm depth leaving 12 cm from top of the container. The effective depth of the Lysimeters was 20 cm.

A piezometer was installed vertically in each Lysimeter in order to monitor the water level. The Lysimeters were allowed to settle down with adding water from the bottom and allowed for pre-settling for 10 days. The outlet of the Lysimeter was connected to a plastic collector with the capacity of 5 liters.

The experiment was conducted with following treatment combinations for 98 days based on the growth period of paddy. The experiment was arranged with complete randomized design with three replicates. The treatment was designed based on the probability analysis of last 80 years of rainfall data. The 6 mm of rainfall was simulated during the experimental period. This amount of rainfall has high probability of occurring in the study area.

D_4 - 4 days interval of simulated rainfall to represent 4 days dry spell

D_{12} - 12 days interval of simulated rainfall to represent 12 days dry spell

D_{20} - 20 days interval of simulated rainfall to represent 20 days dry spell

D_{4p} - 4 days interval of simulated rainfall to represent 4 days dry spell with paddy

Agronomic practices

A 10 cm depth of irrigation was provided at 0, 15, 30, 75 days and urea fertilizer was applied at 0, 16, 31, 46 days at the rate of 125 kg/ha to simulate the field conditions.

Soil and water sampling

Soil samples were collected from the surface at the beginning (0 days), air dried, sieved (2 mm) and analyzed for texture and NH_4^+-N and NO_3^--N were measured. Soil core sample was used to measure the saturated hydraulic conductivity and bulk density. This procedure was continued at 14 days interval until end of the experiment.

Leachate volumes were measured at weekly intervals and subsamples were used to measure NO_3--N (Keeney and Nelson, 1982) and NH_4^+-N (Searle, 1984) in the laboratory. Data were analyzed statistically at 95% confidence level using SAS statistical software.

HYDRUS -1D simulation

The HYDRUS – 1D model was used to simulate a 15 cm soil profile as a single soil layer with observation modes at 5 cm and 10 cm depths. The model printing times were 0, 20, 40, 60, and 80 days represented as (T0), (T1), (T2), (T3) and (T4), respectively. Boundary conditions and initial conditions are shown in Table 1.

Figure 1: The experimental set up with and without plant

Table 1: Initial and boundary conditions used in Hydrus-1D simulation

	Boundary Condition		Initial Condition	
	Upper	Lower	Upper	Lower
Water flow	Atmospheric boundary with surface layer (10 cm)	Free drainage	Pressure head (-15)	Pressure head (-15)
Solute	Concentration flux boundary	Zero gradient	Liquid phase concentration NH_4^+ = 6.59 μg, NO_3^- = 0.93 μg	Liquid phase concentration NH_4^+ = 6.59 μg, NO_3^- = 0.93 μg

Table 2: Input parameters used in solute transport using Hydrus-1D

Solute transport and root up-take parameters	NH_4^+–N	NO_3^-–N
Adsorption isotherm coefficient (K_d)	3.5	0
First-order rate constant for dissolved phase (Sinkwater*)	1	0
Molecular diffusion coefficient in free water, (Diffus.W)	1	1
Longitudinal dispersivity, (Disp) (1/10 of profile length)	1.5	1.5
Maximum allowed concentration for passive up take (cRoot)	30	70
N-fertilizer Applications (μg-N/cm^2)	$cTop_1$	$cTop_2$
0 day – Precipitation assume 1 cm (real 0 cm)	172.5	402.5
16th day – Precipitation 10 cm	172.5	402.5
31st day – Precipitation 10 cm	172.5	402.5
46th day – 17/10/2014 Precipitation assume 1cm (real 0 cm)	172.5	402.5

Results and Discussions

Climatic conditions and management practices

The treatment combinations were subjected to several cycles of varying length of dry days in AWD cycles. Figures 2, 3 and 4 show management practices and climatic conditions for D_4, D_{12} and D_{20}, respectively.

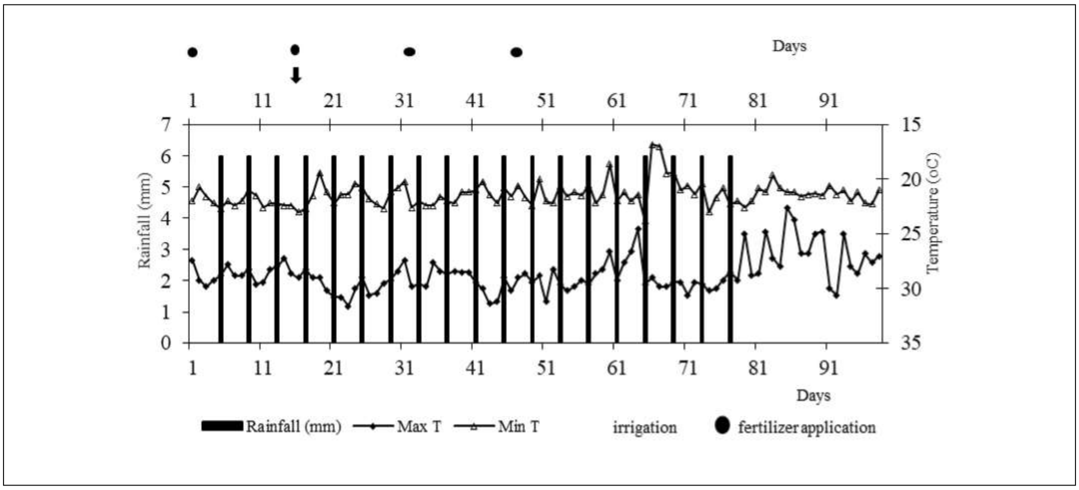


Figure 1: The climatic conditions and management practices for D_4

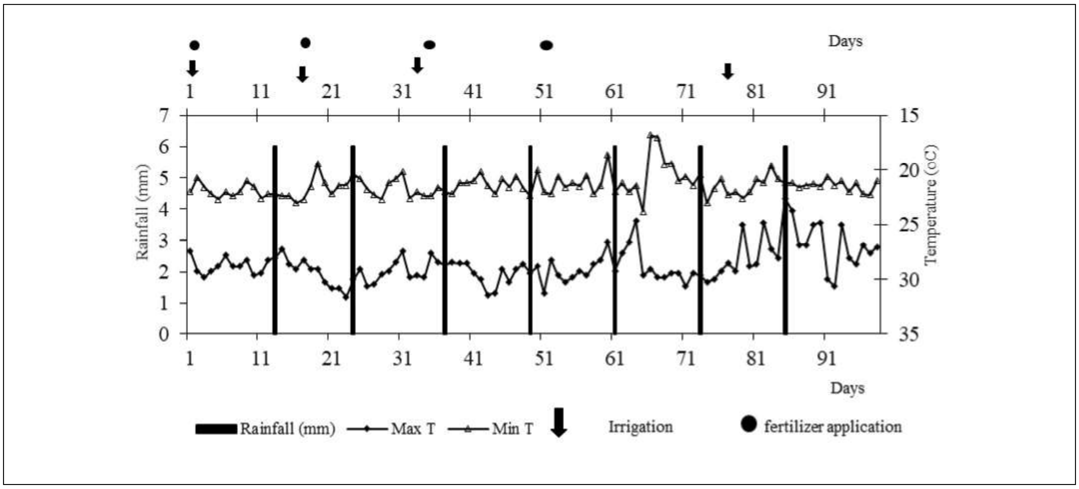


Figure 2: The climatic conditions and management practices for D_{12}

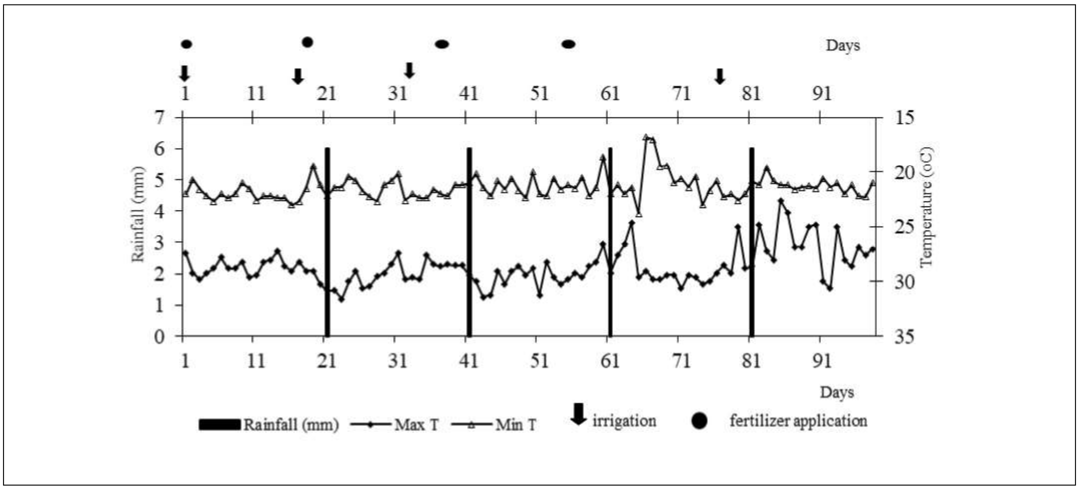
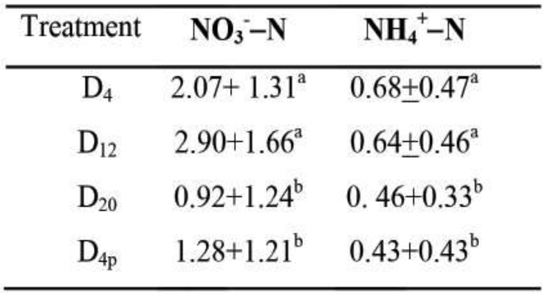


Figure 3: The climatic conditions and management practices for D_{20}

Variation of NO_3^--N and NH_4^+-N concentrations

Table 3 shows the average NO_3^--N and NH_4^+-N concentration in 12 leachate samples in all 4 treatments. ANOVA shows no significant difference between D_4 and D_{12}, (shorter dry spells), but D_{20} (longer dry spell) was significantly different. These results indicate that the shorter and frequent wetting and drying cycle increase the nitrogen loss (both NO_3^--N and NH_4^+-N) through leaching when compared to longer days dry cycles (20 days in this case as tested). Based on these results, we cannot say exact number of dry days needed to have a significant nitrogen leaching since we do not have data in between 12 and 20 days.

Table 3: Nitrate nitrogen (NO_3^--N) and ammonium nitrogen (NH_4^+-N) concentrations (mg/L) in the leachate



Treatment	NO_3^-–N	NH_4^+–N
D_4	$2.07+ 1.31^a$	0.68 ± 0.47^a
D_{12}	$2.90+1.66^a$	0.64 ± 0.46^a
D_{20}	$0.92+1.24^b$	$0. 46+0.33^b$
D_{4p}	$1.28+1.21^b$	$0.43+0.43^b$

The means with the same letters are not significantly differ from each other at α=0.05, mean comparison is at column wise

The effect of irrigation on nitrogen leaching was observed since higher amounts of NO_3^--N and NH_4^+-N were measured after the irrigation. Except the samples collected following irrigation, NO_3^--N loss is high in D_4 followed by D_{12}. The NH_4^+-N loss in leachate is high in D_4 followed by D_{12}, D_{20} and D_{4p}. These results agree with the study by Wijler and Delwiche (1954). Higher nitrogen loss has been observed in soils subjected to periods of alternate drained (aerobic) and flooded (anerobic) conditions (Sepaskhah and Trfteh, 2012)

In the presence of paddy, the loss of nitrogen was less compared to the treatment without plant in the 4 days cycle. The plant should have utilized the nitrogen and the loss was minimized as expected. Therefore, the effect of plant factor on nitrogen loss is cleared in this comparison.

The cumulative leaching of NO_3^--N and NH_4^+-N are shown in Figure 5 and Figure 6, respectively. The total loss of nitrogen was high in D_{12} followed by D_4, D_{20} and D_{4p}. The total loss of nitrogen was calculated based on concentrations and the leachate volumes. The amount of leachate also plays a role in nitrogen losses in AWD cycles. The amount of water applied per irrigation and frequency in AWD cycles is a management option to minimize the effect of nutrient loss. When AWD has a higher frequency, such as D_4 in this case, soil is in saturated conditions. In the saturated condition, nitrification is less and amount of NO_3^--N available for leaching is less. On the other hand, nitrification adversely is affected by extreme drought condition as in D_{20}.

Figure 6 shows the cumulative NH_4^+-N loss in all treatments. The cumulative loss of NH_4^+-N is varied as $D_4 > D_{12} > D_{20} > D_{4p}$, where a significantly low NH_4^+-N loss was in D_{4p} compared to D_4. Table 4 summarizes the inorganic – N recovery efficiency for different drying cycles. The recovery efficiency is varied as $D_4 > D_{4p} > D_{12} > D_{20}$.

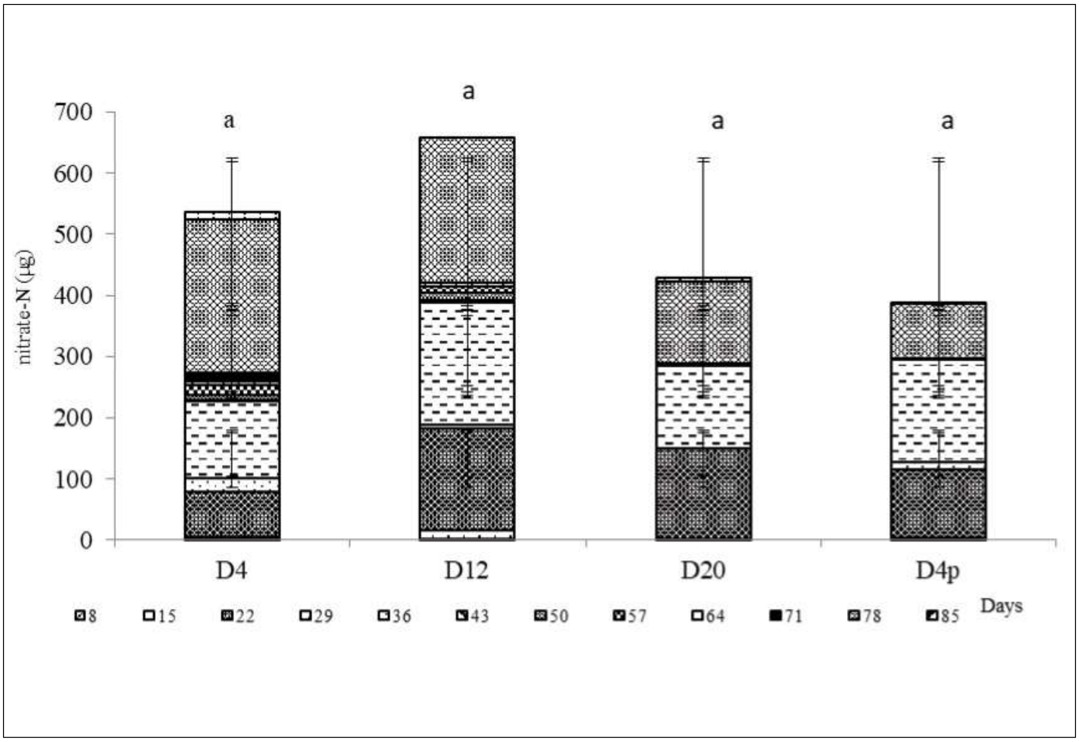


Figure 5: Cumulative nitrate – N loss through leachate for treatments

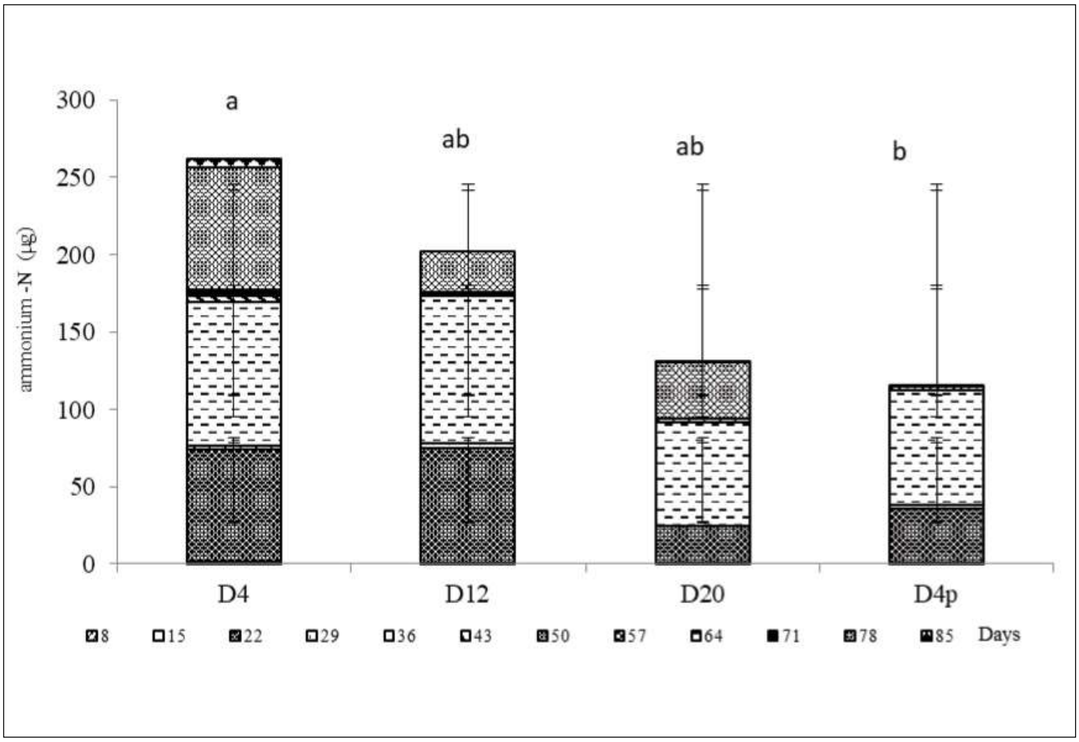


Figure 6: Cumulative ammonium – N loss through leachate for treatments

Table 4: The recovery of inorganic – N with treatment

AWD intervals	Paddy plant	N-added (mg/g of soil)	Initial total mineral N (ppm)	Final total mineral N (ppm)	Nitrogen retained (%)
4 days (D_4)	No	26.07	26.04	20.24	38.85
12 days (D_{12})	No	26.07	70.40	21.31	22.09
20 days (D_{20})	No	26.07	90.11	22.02	18.95
4 days (D_{4p})	Yes	26.07	30.07	20.70	36.87

Simulated water flow

Water flow was simulated with Hydrus-1D. A remarkable increase in the observation node's water content for all treatment is observed during the irrigation day and decreases with time. In all treatments, the water content at 10 cm observation node was higher than that at 5 cm node.

Also the 5 cm node shows a quick loss of water and quick recovery in simulation of water. All treatments shows similar pattern of the fluctuations with their respective water application. The D_{4p} (4 days dry spell with plant) shows a reduced amount of water at the 5 cm observation node at 40 to 98 days. This may be associated with the root water uptake by the plant with the growth stages.

Simulated water flux

The water flux value remains positive, means there are no water stress in the experimental setups during the study period. The effective root zone depth was 12 cm, because the model simulates the water flux above 12 cm depth in negative direction.

Model validation

The model was validated by assumption of fate of Urea with different combinations of NH_4^+-N and NO_3^--N. This fraction in the soil depends on soil pH, moisture level, aeration and microbial activity. The fertilizer applied undergoes through the hydrolysis process resulting NH_4^+, NO_2^-, NO_3^- and N_2. The NH_4^+ and NO_3^- can be taken up by plants. The Hydrus-1D simulated the mean concentration of nitrogen in the leachate and solute balance error (%) for assumptions on fate of Urea. With increase in the fraction concentration, NH_4^+-N and NO_3^--N show an increasing trend.

Error balance increases for NO_3^--N and decrease for NH_4^+-N. Most suitable fraction for NO_3^--N leaching was 30n_70N (urea hydrolyzed into 30% of ammonium and 70% of nitrate) for all treatments. The Hydrus-1D simulated leaching loss of NO_3^--N was 285, 1150, 1140 and 1090 kg/ha for D_4, D_{12}, D_{20} and D_{4p}, respectively. Except for the D_4, other treatments show a similar pattern of changes for both simulated and measured values. The correlation between the measured and simulated values (R^2) were; 0.89, 0.79, 0.74 and 0.69 for D_4, D_{12}, D_{20} and D_{4p}, respectively.

The measured fertilizer used efficiency was calculated using fertilizer input and leachate output, for all treatments. The simulated fertilizer use efficiency was also calculated indirectly from fertilizer input and bottom solute flux (represent leachate). The measured fertilizer use efficiency was 65.3, 27.9, 38.3 and 53.8% for D_4, D_{12}, D_{20} and D_{4p}, respectively. These values varied as 74.0, 82.9, 83.3 and 77.1% under simulated conditions for D_4, D_{12}, D_{20} and D_{4p}, respectively.

According to Patrick and Reddy (1974), the NO_3^--N leaching in AWD was higher than continuous aerobic conditions, but it was higher under continuous aerobic condition than anaerobic condition. The soil used in this experiment was subjected to a 17 mm/day infiltration rate. Therefore, the applied irrigation water could be escaped from the soil column in 9 days.

Simulated solute flux

The solute flux (NO_3^--N and NH_4^+-N) at the surface fluctuates with the split application of the fertilizer. Even though all treatments provided with the same amount of fertilizer, the fluctuation was high during the 2nd and the 3rd application where, the fertilizer was applied with irrigation water. Figure 7 and Figure 8 describe the variation of NH_4^+-N and NO_3^--N at surface with time, respectively. In all treatments, the surface concentration of NH_4^+-N and NO_3^--N shows the similar pattern. The surface NH_4^+-N concentration shows increasing and then decreasing pattern with maintaining $D_{20} > D_{12} > D_4 > D_{4p}$ rates, mainly because of plant uptake of NH_4^+-N.

The concentration of NO_3^--N shows an increasing pattern with time and shows

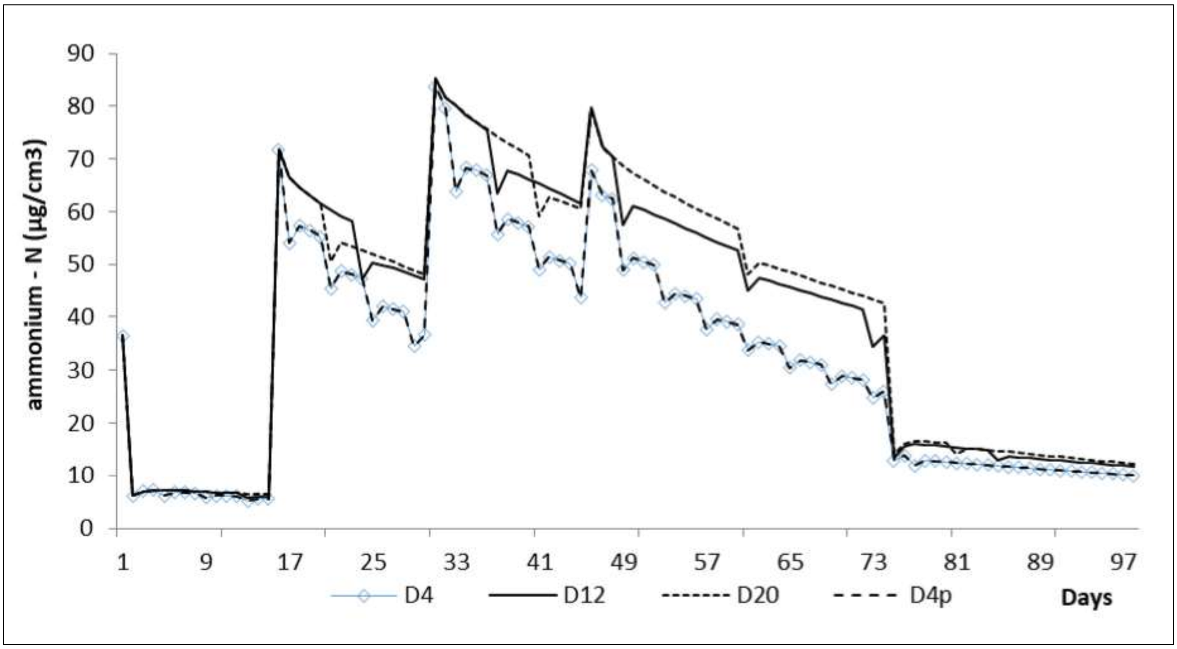


Figure 7: Simulated surface concentration of ammonium – N (NH_4^+-N)

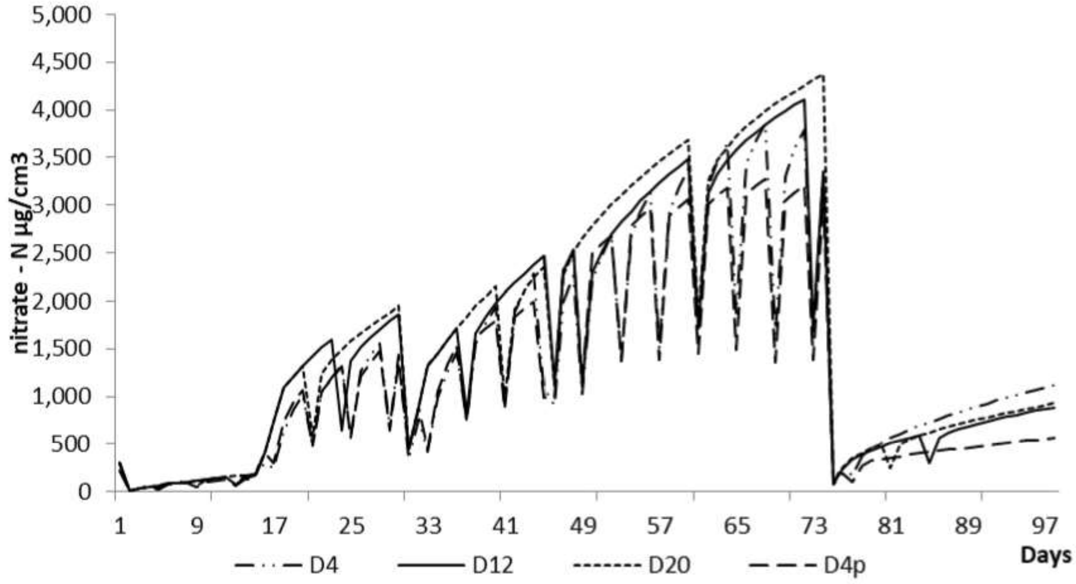


Figure 8: Simulated surface concentration of nitrate – N (NO3-N)

the decreasing in flux for the period of irrigation. The surface concentration is very high than the NH_4^+-N. During the period of experiment for 90 days, the recorded minimum temperature was greater than 20°C. This situation favors the conversion of urea in to NO_3^--N than to NH_4^+-N. With the application of irrigation water, surface concentration reduces considerably. With availability of excess water, the leaching potential of negatively charged NO_3^--N is high. The surface concentration of NO_3^--N varied as $D_{20} > D_{12} > D_4 > D_{4p}$.

In all treatments, the concentration of both nitrogen ions shows similar patterns. The reduction of NH_4^+-N and increases in NO_3^--N concentration in the later part might be due to two factors; scarcity of the water to absorb by plants or leached out and change in the growth stage of the plant. During the later part due to the reduced water, soil leads to more aerobic conditions and formation of NO_3^--N from urea.

Conclusions

The Lysimeter study further clarified the effect of the length of dry spells and the plant on nitrogen dynamics. The aerobic condition towards the end of growing period creates the decreasing trend of NH_4^+-N and increasing trend of NO_3^--N. The irrigation interval would have to be decided between 12 to 20 days along with the rainfall variability to reduce the nitrogen loss in paddy fields. The Hydrus-1D could be usedto simulate the impact of alternative wetting and drying on NO_3^--N loss and for understanding of nitrogen dynamics under different agronomic conditions.

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