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Forms of nitrogen in runoff and sediments under a *Solanum macrocarpon* (L.) Moench farm after urea fertilizer application

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Abstract

Runoff from agricultural fields is major of source nitrogen pollution of surface water resources. The impact of the menace on surface water directly emanating from agricultural fields in different agroecologies has not been fully understood. Applying different urea rates, the runoff and sediments generated from *Solanum macrocarpon* plots after rainfall and irrigation events were analyzed for nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N) and ammonium-nitrogen (NH_4-N) in a one-year study involving two seasons. Significant nitrite-nitrogen, nitrate-nitrogen and ammonium-nitrogen response to the treatments were observed in 17 – 57% of the runoff events, and nitrate-nitrogen of sediments. Runoff NO_2–N concentrations from 80 kg N ha^{-1} (CA) was in many cases higher than values in plots with lower rates. Commonly, runoff's NO_3–N from plots with urea was higher than controls' in rainforest but within the urea treated plots, the differences were insignificant. In derived savanna about 67% of significant comparison of runoff NO_3–N were between control and plots with urea while about 33% were due to differences noticed between 20 – 60 kg N ha^{-1} (MD 1 – MD 3) and MD 1 - CA. Moreover, NH_4–N in runoff increased with urea in both agroecologies. In conclusion, NH_4–N in runoff increased with applied urea while the responses of other nitrogen forms were inconsistent. Based on World Health Organization's (WHO) standard, runoff's NO_2–N from CA in derived savanna and all treatments in rainforest tended to be harmful to humans if it enters drinking water. However, NO_3–N released from the plots seemed not harmful.

Keywords: *Urea, Runoff, Nitrite nitrogen, Nitrate nitrogen, Ammonium-nitrogen*

Introduction

Surface runoff of water from agricultural plots is an important pathway for the contamination of surface and underground water bodies. Runoff results when rainfall or irrigation exceeds infiltration rate. This usually leads to erosion of farm plots. Studies on river flow (Powers, 2007), streams and lakes (Jabbar and Grote, 2019), tile drainage (Zang *et al.*, 2015) and runoff (Smith *et al.*, 2015) from agricultural fields show strong evidences that fertilizers contribute a large quantity of nutrient loads to surface water bodies. Nutrients such as nitrogen, phosphorus, potassium and salts from fertilizers dissolved in runoff, as well as contaminants such as heavy metals, pesticides and pathogens attached to sediments and transported by runoff are major concerns to surface water quality. United State Environmental Protection Agency, USEPA (2003), reported that more than one-third of rivers and streams segments assessed in the United States are impaired for their use as a result of polluion from nutrients and sediments entering the waterways from agricultural fields while Goolsby and Battaglin (2000) observed that with a combination of nutrient loads and changes in water condition, a region along the coast of Louisiana is rated ecologically dead most summers. Accordingly, Xia *et al.* (2020) averred that

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management of non-point source pollution as a result of runoff from farmlands is already a concern for USEPA and United State Department of Agriculture (USDA). About 870 metric tons of vegetables was produced in 2018 globally, with Nigeria's total production standing at 16 metric tons (FAOSTAT, 2020). However, the increasing use of nitrogen compounds such as urea as fertilizers for vegetable production has the potential of continuing the release of nitrogen oxides, ammonia (NH_3), ammonium (NH_4^+), nitrites (NO_2) and nitrates (NO_3^-) to the environment (Galloway *et al*., 2003). Health issues such as blue baby syndrome (WHO, 2011); gastrointestinal, urinary and colorectal cancer in humans (Villanueva *et al*., 2014 and Espejo-Herrera *et al*., 2016); and food poisoning in animals (Longnecker and Daniels, 2001) have been linked to the presence of nitrates and nitrites, at elevated concentration, in water and animal feeds. Ammonium has also been indicted in contributing to total ammonium toxicity in aquatic organism under the condition of high pH and temperature (Liu *et al*., 2014). Moreover, the build-up of ammonium and nitrite in soil have been found to adversely affect plant growth (Starks & Richards, 2008). In a study on the relationships between fertilizer N use and pollution of both surface and groundwater at watershed and global scales, Bijay – Singh and Eric (2021) concluded that crops use only about 50% of applied N while only small portion is lost through different mechanisms of N loss at the time of application while the rest was in form of organic N pool. The organic N mineralizes and is either taken by plant or lost. Furthermore, they believed that the current scale of freshwater pollution was a result of accumulation of current and decades of past application of fertilizers and manures. However, to specifically relate N pollution with farming activities, Liu *et al.* (2010) evaluated global annual inflows and outflows of N into and out of farmlands and observed that about 11.4 Tg N in excess of N input was removed through erosion and leaching of nitrates. Extensive research has been conducted on the impact of nitrogen fertilizers on the leaching of the nutrient out of the root zone. Several studies involving leaching experiments from tile drainage and lysimeters (Wallman and Delin, 2022), modelling of nitrate from empirical data from agricultural fields (Børgesen *et al*., 2022), and vertical and lateral leaching of nitrates (Iqbal, 2006) showed that nitrate leaching increases with increase in both organic and inorganic sources of nitrogen. Nitrate leaching has also been found to be high in soil under vegetables cropping because of their shallow rooting depth (Barros *et al*., 2019). Studies on leaching from agricultural fields cut across different approaches, zones and regions characterized by different cropping and farming systems as well as agroclimatologies. In contrast, nutrient loss by runoff from agricultural activities has not been extensively investigated. Few of runoff studies investigating the potentials for runoff nutrient loss to the field plot environment includes Zhao *et al.* (2012), who observed that more than 85% of N loss were from runoff generated from flooded irrigation under rice-wheat rotation in Taihu Lake region of China. Working in similar environment under a more water use efficient method of irrigation that significantly reduced runoff loss, Huang *et al.* (2022) observed that the concentration of nutrients did not decrease in surface runoff. Another study by Ma *et al.* (2021) showed that the amount of fertilizer used was the greatest driver of dissolved nitrogen loss in runoff in a vegetable field under a simulated rainfall and trough experiment. They however admitted that one of the limitations of their study was the use of confined soil environment in trough, suggesting that experiments in a real field condition could give a better analyses of the relationship between the vegetables, the real soil environment and surface runoff. Moreover, there is still dearth of information on the potentials of runoff for immediate field environment contamination in agroecological system and modal soil types characteristic of vegetable growing areas where nitrogen fertilizers are used in large quantities. Further information on fertilizers' impact on surface runoff directly emanating from vegetable plots where nitrogen fertilizers such as urea are used, are required (Fischer *et al*., 2010; Xia et *al*., 2020; Bijay–Singh and Eric, 2021). In the study area under which this research was conducted, the modal fertilizer rate usually used by local farmers is 80 Kg N ha^{-1}. This fertilizer rate is considered to be wasteful and have a high tendency of polluting farm environment. Comparing micro-doze urea rates plots, to which there have been basal application of organic amendments to maintain the poor structural condition of the soil, with the local farmers' conventional urea application; this study sought to investigate the impact of the fertilizer rates on the growth of the vegetables used as test crop and on runoff from the immediate field environment. This is particularly important for N pollutants such as nitrites and ammonium as well as nitrates which have received much attention as an important non point

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source agricultural pollutant (Bijay–Singh and Eric, 2021). There is therefore a need to monitor the impact of different urea fertilizer rates on runoff as well as sediments from vegetable plots, some of which eventually join underground and surface water. The objective of this study is to investigate nitrites-nitrogen, nitrate-nitrogen, ammonium-nitrogen in runoff and sediments nitrate-nitrogen under these fertilizer rates.

Materials and Methods

The study was carried out at the Teaching and Research Farm, Obafemi Awolowo University (T&RF, OAU), Ile-Ife, Osun State, Nigeria (which lies between Latitudes 7°32'N and 7°33'N, and Longitudes 4°32'E and 4°40'E) and National Biotechnology Development Agency (NABDA), Ogbomoso, Oyo State, Nigeria (which lies between Latitudes 8°6'16.9"N and 8° 6' 46"N and Longitudes 4°14'13"E and 4°18'42”). The field study which was carried out close to a period of one year consisted of two cropping seasons. These included dry season (from October, 2017 to March, 2018) and wet season (from April to August, 2018) experiments. The T&RF, OAU is in a rainforest zone with mean annual rainfall of 1500 mm while NABDA, Ogbomoso is in a derived savanna zone with 1296 mm mean annual rainfall. Rainfall patterns are bimodal in both locations of the study, with peaks in June/July and September/October in the T&RF, OAU while rainfall peaks are in July and September in NABDA, Ogbomoso. The soil of both study locations is classified as Typic Kandiustalf according USDA system of classification (Olasoji *et al.*, 2022; Soil Survey Staff, 2014). The test crop grown was an eggplant, *Solanum macrocarpon* (L.) Moench and it was raised for its shoot as vegetables. The vegetable was raised in nursery for about three weeks to an average height of 15 cm before it was transplanted to a 6 m^2 prepared plots at a spacing of 10 cm within row and 20 cm between rows. The plots were prepared as heaps of topsoil of about 30 - 40 cm high. Runoff and sediment were collected from the sides of the plots with installed plastic containers. The urea fertilizer rates (Table 1) was surface applied at rates of 20, 40, 60, and 80 kg N ha^{-1} with zero urea plot as the control. The experiment was laid out in randomized complete block design with four replications. The 80 Kg N ha^{-1} represents conventional application (CA) and it is farmers' fertilizer application practice in the study area while 20, 40, 60 are the microdosed rates. Apart

Table 1. *Fertilizer Rates and their representations*

Fertlizer Rates (kg N ha^{-1})	Representation
0+OA	CT
20 + OA	MD 1
40 + OA	MD 2
60 + OA	MD 3
80	CA

from CA plots, three kilograms of organic amendment (OA) constituting 105 g N was applied as basal application on each plot, two weeks before planting. The fertilizer produced from household wastes, by Sunshine Organic Fertilizers Ltd. contained 3.5% N (Ondo State Government, 2012). Application of 80 Kg N ha $^{-1}$ without organic amendments, OA, is the farmers' practice represented as CA treatment. The plots were irrigated three times a week during the dry season while supplemental irrigation was done once or twice a week during the wet season, depending on the frequency and amount of rain. The frequency of irrigation represented the farmers' practice. Surface runoff water and soil sediment were collected from each plot, after each rainfall and irrigation event that generated runoff, for subsequent laboratory analyses. The eggplants got established forming sufficient canopy to smother weeds on the plots. Few weeds that emerged on the plot were controlled by hand picking. Runoff samples collected from the plots were analyzed immediately on the day of collection while those which could not be analyzed immediately were frozen until analysis. Runoff sediment was extracted with 0.01 N $CaCl_2$ as described by Houba *et al.* (2000). The nitrate, nitrite and ammonium content of the runoff water and extract from sediment were determined by colorimetric method using Seal HR3 Auto Analyzer with method number G- 109-94 Rev 8 (Multitest MT7/MT8) at wavelength of 660 nm. Data obtained from the study were analyzed using the generalized linear model method with significant means compared with pairwise multiple comparison method ($p <= 0.05$) to understand the responses of the runoff and its sediment nitrogen species to the quantity of fertilizer applied. The generalized linear model directly compared the contrast between runoff and sediments of every two different treatments of the fertilizer and control applied in the study. The first three datasets for nitrite and nitrate were the runoff events in dry season while the last four dataset were from runoff in wet season cropping cycle.

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Results and Discussion

Effect of Urea–N fertilizer on the growth of eggplant

Table 2 showed the growth of eggplant at the point of first harvest. This result showed that the fertilizer rates did not have any significant effects on the height of eggplant in both seasons in the derived savanna zone and in wet season in rainforest. Also, in the rainforest dry season where there were some level of increased growth of the plant with fertilizer rates applied, no clear pattern could be established. However, in both seasons in rainforests, conventional farmers application rates lead to increased eggplant's growth compared to control. This seemed to agree with the findings of Adeyeye *et al.* (2014) and Ademiluyi *et al.* (2016) where they reported significantly lower height of eggplant after two and four weeks respectively in control compared to nitrogen levels in the fertilizer applied. The commonly observed non significantly increase eggplant height with fertilizer rates applied in this study could be as result of the blanking effects of basal applications of organic amendments in the CT, MD 1, MD 2 and MD 3 which could have masked the effect of urea rates applied to the plots.

Fertilizer Rate	Rainforest		Derived Savanna	
	Wet Season	Dry season	Wet Season	Dry season
CT	31.9b	27.8d	33.8a	21.8a
MD 1	42.8a	34.4c	41.3a	26.6a
MD 2	42.4a	37.3bc	40.4a	26.4a
MD 3	41.2a	39.4ab	43.2a	26.0a
CA	45.2a	41.1a	41.2a	28.8a

Means with the same letters in the same column are not significantly different from each other

Table 2
Effect of urea fertilizer on the height (cm) of eggplant

Background information on nitrogen content of rain and irrigation water, and runoff

The nitrite and nitrates content in rain and irrigation water are as shown in Table 3. Rain water nitrogen contents were obtained from previous studies conducted in the study areas. This data showed nitrate in irrigation water were higher in the rainforest compared the derived savanna area, a reason which can be a result of different water sources. Irrigation water in the rainforest was from a well near an active farming activities while in the derived savanna, the water was from a large dam; thus suggesting that the irrigation water could have been influenced by the intensity of activities around it.. This is supported by the findings of Okoya *et al.* (2016) who reported that land use and agricultural activities around the rainforest study location influenced the chemical properties of rainwater. About 3.75 Litres of water were usually collected after each runoff event. However, the amount of sediment were not quantified. Not all runoff events generated adequate amount of sediments for analyses. This is why there were fewer soil sediments nitrate data in derived savanna compared to the rainforest study area.

Forms of Nitrogen	Rainforest			Derived Savanna		
	Rain Water	Irrigation Water		Rain Water	Irrigation Water	
	mgL^{-1}					
Nitrites	-	**0.27**	*0.23*	**0.85***	**0.40**	*0.05*
Nitrates	**1.00****	**1.70**	*0.81*	**0.42***	**1.14**	*2.04*

No data available, *Abegurin *et al.*, 2017; ** Okoya *et al.*, 2016.
The numbers in bold and italics are the means and standard deviations of the means respectively.

Table 3
Nitrate and Nitrite Nitrogen of rain and irrigation water in the study areas

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Effect of Urea–N fertilizer on nitrite-nitrogen (NO_2–N) content in Runoff

In Tables 4 and 5 The standard deviation values showed that, except in some instances at *DRS* 2, 4 (MD 3), 5 (CA), 7 (MD 2 and MD 3); RFR 4 (MD 2 and CA), RFR 7 (CT) there were not much variations in the concentrations of runoff nitrites from the same plots. This was because the standard deviations of mean were in most cases low compared to the means. This showed that in most cases the nitrite concentrations had consistently similar values in plots with the same treatments. Significantly higher nitrite was the concentrations of runoff nitrites from the same plots. This was because the standard deviations of mean were in most cases low compared to the means. This showed that in most cases the nitrite concentrations

Table 4

Pairwise multiple comparison of means of nitrite concentration in runoff under different urea treatments in the derived savanna.

Urea rates Kg N ha^{-1}			0+OA	20+OA	0+OA	60+OA	80
			mg L^{-1}				
DRS 1				mg L^{-1}			
CT	**0.57**	*0.28*	0	0.03ns	0.04ns	0.07ns	0.09ns
MD 1	**0.54**	*0.19*		0	0.07ns	0.10ns	0.12ns
MD 2	**0.61**	*0.12*			0	0.03ns	0.05ns
MD 3	**0.64**	*0.15*				0	0.03ns
CT	**0.66**	*0.07*					0
DRS 2							
CT	**0.04**	*0.04*	0	0.24ns	0.06ns	1.38ns	1.86ns
MD 1	**0.27**	*0.27*		0	0.18ns	1.14ns	1.62ns
MD 2	**0.10**	*0.14*			0	1.32ns	1.79ns
MD 3	**1.42**	*2.00*				0	0.47
CT	**1.89**	*2.26*					0
DRS 3							
CT	**0.04**	*0.03*	0	0.05ns	0.43ns	0.25ns	0.46*
MD 1	**0.09**	*0.06*		0	0.39ns	0.21ns	0.42ns
MD 2	**0.47**	*0.37*			0	0.18ns	0.03ns
MD 3	**0.30**	*0.14*				0	0.21ns
CT	**0.50**	*0.39*					0
DRS 4							
CT	**0.02**	*0.01*	0	0.01ns	0.17ns	0.47ns	0.39ns
MD 1	**0.03**	*0.01*		0	0.16ns	0.45ns	0.38ns
MD 2	**0.19**	*0.11*			0	0.30ns	0.22ns
MD 3	**0.49**	*0.64*				0	0.08ns
CA	**0.41**	*0.25*					0
DRS 5							
CT	**0.03**	*0.01*	0	0.11ns	0.14ns	0.25ns	0.86ns
MD 1	**0.14**	*0.08*		0	0.03ns	0.14ns	0.75ns
MD 2	**0.17**	*0.10*			0	0.11ns	0.72ns
MD 3	**0.28**	*0.07*				0	0.61ns
CA	**0.89**	*1.29*					0
DRS 6							
CT	**0.02**	*0.01*	0	0.05ns	0.10*	0.12*	0.12*
MD 1	**0.07**	*0.04*		0	0.05ns	0.06ns	0.06ns
MD 2	**0.13**	*0.07*			0	0.01ns	0.01ns
MD 3	**0.14**	*0.04*				0	0.00ns
CA	**0.14**	*0.03*					0
DRS 7							
CT	**0.36**	*0.14*	0	0.40ns	2.10ns	7.77ns	11.80*
MD 1	**0.75**	*0.24*		0	1.70ns	7.37ns	11.41*
MD 2	**2.45**	*3.62*			0	5.67ns	9.71*
MD 3	**8.12**	*8.18*				0	4.04ns
CA	**12.16**	*7.77*					0

Note
Kg N ha^{-1}, mg L^{-1}, DRS, OA, ns, and *, represent kilogram ni-trogen per hectare, milli-gram per liter, Derived Sa-vanna, Organic amend-ment, not significant and significant at $p <= 0.05$ respectively.

Numbers in bold and italics are means of runoff nitrite and standard deviation of mean concentration respectively.

DRS 1 to 3 are for dry season runoff while *DRS* 4 to 7 are for wet season runoff

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Urea rates			0+OA	20+OA	40+OA	60+OA	80
Kg N ha^{-1}					mg L^{-1}		
RFR 1				mg L^{-1}			
CT	**0.47**	*0.16*	0	0.05ns	0.15ns	0.20 ns	0.82*
MD 1	**0.42**	*0.01*		0	0.19ns	0.25 ns	0.87*
MD 2	**0.61**	*0.17*			0	0.06 ns	0.68*
MD 3	**0.67**	*0.08*				0	0.62*
CA	**1.29**	*0.70*					0
RFR 2							
CT	**0.00**	*0.00*	0	0.00ns	0.10*	0.16*	0.23*
MD 1	**0.00**	*0.00*		0	0.10*	0.16*	0.23*
MD 2	**0.10**	*0.11*			0	0.06ns	0.13*
MD 3	**0.16**	*0.03*				0	0.07ns
CA	**0.23**	*0.03*					0
RFR 3							
CT	**0.15**	*0.06*	0	3.20ns	3.72*	1.85ns	4.20*
MD 1	**3.35**	*1.91*		0	0.51ns	1.35ns	1.00ns
MD 2	**3.86**	*2.13*			0	1.87ns	0.49ns
MD 3	**2.00**	*1.00*				0	2.35ns
CA	**4.35**	*3.51*					0
RFR 4							
CT	**0.05**	*0.04*	0	0.09ns	0.97ns	0.71ns	2.35*
MD 1	**0.14**	*0.05*		0	0.88ns	0.61ns	2.26ns
MD 2	**1.02**	*1.31*			0	0.27ns	1.38ns
MD 3	**0.76**	*0.48*					1.64ns
CA	**2.40**	*2.60*					0
RFR 5							
CT	**0.13**	*0.19*	0	0.03ns	0.11ns	0.17ns	0.29*
MD 1	**0.10**	*0.03*		0	0.13ns	0.20*	0.31*
MD 2	**0.23**	*0.18*			0	0.06ns	0.18ns
MD 3	**0.30**	*0.04*				0	0.11ns
CA	**0.41**	*0.05*					0
RFR 6							
CT	**0.74**	*0.30*	0	1.59ns	2.97ns	11.70*	41.31*
MD 1	**2.33**	*1.20*		0	1.38ns	10.11*	39.72*
MD 2	**3.71**	*0.69*			0	8.74*	38.34*
MD 3	**12.45**	*2.79*				0	29.60*
CA	**42.05**	*11.51*					0
RFR 7							
CT	**0.61**	*0.89*	0	0.00ns	0.08ns	1.29ns	3.00*
MD 1	**0.61**	*0.35*		0	0.08ns	1.29ns	3.01*
MD 2	**0.69**	*0.65*			0	1.21ns	2.93*
MD 3	**1.90**	*0.65*				0	1.72ns
CA	**3.62**	*1.15*					0

Table 5
Pairwise multiple comparison of means of nitrite concentration of runoff under different urea treatments in the rain forest.

Note
Kg N ha^{-1}, mg L^{-1}, DRS, OA, ns, and *, represent kilogram nitrogen per hectare, milligram per liter, Rain forest, Organic amen-dment, not significant and significant at p <= 0.05 respectively.

Numbers in bold and italics are means of runoff nitrite and standard devia-tion of mean concentra-tion respectively.

DRS 1 to 3 are for dry season runoff while *RFR* 4 to 7 are for wet season runoff.

had consistently similar values in plots with the same treatments. Significantly higher nitrite was ob-served in CA (80 kg N ha^{-1}) plots compared to CT (0 kg N ha^{-1} + OA) plots at derived savanna runoff events 3, 6, and 7 (DRS 3, 6 and 7). Similarly, higher NO_2–N in runoff was recorded in MD 3 (60 kg N ha^{-1} + OA) and MD 2 (40 kg N ha^{-1} + OA relative to CT at DRS 6. However, most of the runoff events did not show any difference in means of nitrite concen-tration due to the quantity of urea fertilizer applied. Only few instances at DRS 7 where CA plots had significantly higher runoff NO_2-N concentration compared to each of MD 1 (20 kg N ha^{-1} + OA) and MD 2 plots, suggested that concentration of nitrite in runoff emanating from the plots increased with urea fertilizer use. In rainforest (RFR) location, runoff from CA

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plots had higher NO_2–N than other urea rates and control at RFR 1 and RFR 6 (Table 5). Similar results were observed in RFR 2 and 7 where all other urea treated plots except MD 3 plots generated significantly lower nitrite contaminants concentrations. Higher runoff NO_2–N concentrations were observed in MD 3 plots compared to most of the plots on which lower urea rates were applied at runoff events 2 and 6 in the rainforest location. Similarly, MD 2 plots had significantly higher runoff NO_2–N concentrations than MD 1 and CT plots in RFR 2. This result indicated that in derived savanna, three of the seven runoff events showed some degrees of significant plot wise differences in nitrite concentration due to the quantity of urea applied while in rainforest, all the runoff events indicated significant differences in mostly between MD 3 and CA plots versus plots with lower urea rates. From the foregoing, runoff nitrite contamination seemed to increase with the quantity of urea applied in plots where significant differences in means of NO_2–N concentrations was recorded. This observation was most common in CA plots where higher amount of runoff nitrite was recorded relative to other urea treated plots and control. The concentration of nitrite in the runoff water was not proportionate to the amount of fertilizer applied in this study. This is probably because other factors apart from quantity of urea applied could influence the degree of runoff contamination by N. It is important to note that nitrite is an intermediate product of urea conversion to nitrate, and factors such as weather, soil condition and microbial properties could interplay, apart from urea concentration, in complex reactions to influence the amount of nitrite in runoff. Fang *et al.* (2012) and Shetty *et al.* (2019) reported that soil nitrite content increased with increase in urea rate within 24 hours of application, suggesting that the presence of nitrite in soil was short - lived and it would be converted to other nitrogen forms if there were no runoff within the short period. This therefore suggested there are many pathways through which nitrogen species are lost in addition to its nitrite forms contaminating runoff emanating from farm plots. This result is similar to the finding of McSwiney and Robertson (2005) who reported non-linear N leaching loss in relation to amount of nitrogen fertilizer applied. Similarly, this work also compared to the finding of Easton and Petrovic (2004) who observed that levels of runoff concentration of N did not correspondingly rise with the amount of nitrogen fertilizer applied Their findings indicated that dense canopy of shoot in plots with fertilizer treatments favoured higher crop uptake, lower runoff and hence reduced nutrient concentration in runoff. However, in this study dense canopy of eggplant was hardly observed. This was because the vegetable was grown for its leaf, hence before dense canopy which could influence nutrient uptake and nitrogen concentration in runoff was formed, the shoot had always been harvested. A possible reason why impact of urea was less in derived savanna compared to rainforest could be because of differences in the agro-ecologies. It has been reported that increase in temperature and soil moisture up to saturation increases the rate of urea volatilization (Ernst & Massey, 1960; Al-Kanani *et al.*, 1991; Ni & Pacholski, 2022). The rainforest is more humid, generally of lower temperature and solar radiation than the derived savanna zone, in addition sandier soil in the latter. Since urea volatilization and other processes of its conversion are influenced by these prevailing weather conditions, it is reasonable to expect a different pattern in runoff concentration of nitrite and other forms of N with the different urea rates. If the recorded mean nitrite concentration in runoff from CA plots at DRS 2 and 7 from derived savanna entered the surrounding water bodies, consumption of surface water in the area could pose serious hazard to human health. Similarly, if there are no dilution and loses of runoff water downslope, almost all the runoff events emanating from the rainforest are dangerous if taken by human because the values of nitrite recorded at these points were above the recommended allowable limit of 0.9 mgL^{-1} in drinking water (WHO, 2017).

Effect of Urea-N fertilizer on nitrate-nitrogen (NO_3–N) content of runoff

Similar to the runoff nitrite concentrations, it can be observed from standard deviation values in Tables 6 and 7, that in most cases, there were low level of variation within the same treatment, except DRS 1, where almost all the plots from the same fertilizer level seemed to have large variations in runoff nitrate concentrations. Table 6 showed that urea rate did not contribute significantly to nitrate concentration of runoff water in derived savanna agro-ecology. Significant differ-rences were however recorded only in DRS 3 where runoff in MD 2 plots had higher nitrate concentration than CT plots, DRS 7 where CA and MD 3 plots gene-rated higher nitrate concentration than CT plots and also in DRS 5 where CA plots had

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lhigher nitrate evel than CT. Within the urea treated plots, MD 3 and CA plots generated higher level of nitrate in runoff than MD 1 plots at DRS 2 and 5 respectively. Similarly, in rainforest zone (Table 7), plots with urea rates had higher nitrate than CT plots at RFR 5. Also at RFR 4 and 6, MD 2 and CA plots respectively generated hi gher level of nitrate than control. However, at RFR 3, nitrate concentration in CT plots were higher than the amount recorded in plots with urea application. There was no clear pattern in variation of nitrates in runoff with the fertilizer rates applied contrary to Ma *et al.*, (2021) who repor-

Table 6
Pairwise multiple comparison of means of nitrate concentration of runoff under different urea treatments in the derived savanna.

Urea rates Kg N ha^{-1}			0+OA	20+OA	40+OA	60+OA	80
			mg L^{-1}				
DRS 1							
CT	**1.63**	*2.02*	0	1.02ns	1.23ns	0.24ns	1.42ns
MD 1	**0.61**	*0.26*		0	0.20ns	0.79ns	0.40ns
MD 2	**0.41**	*0.42*			0	0.99ns	0.20ns
MD 3	**1.40**	*2.52*				0	1.19ns
CA	**0.21**	*0.25*					0
DRS 2							
CT	**5.39**	*1.96*	0	3.15ns	1.32ns	1.95ns	0.65ns
MD 1	**2.24**	*2.07*		0	1.83ns	5.10*	3.80ns
MD 2	**4.07**	*1.65*			0	3.28ns	1.98ns
MD 3	**7.34**	*1.27*				0	1.30ns
CA	**6.04**	*3.92*					0
DRS 3							
CT	**0.31**	*0.14*	0	1.60ns	3.56*	1.30ns	1.99ns
MD 1	**1.91**	*0.81*		0	1.96ns	0.30ns	0.38ns
MD 2	**3.87**	*2.86*			0	2.24ns	1.57ns
MD 3	**1.61**	*0.78*				0	0.68ns
CA	**2.30**	*0.86*					0
DRS 4							
CT	**0.08**	*0.03*	0	1.11ns	0.91ns	1.56ns	1.97ns
MD 1	**0.19**	*0.11*		0	0.81ns	1.44ns	1.86ns
MD 2	**0.99**	*0.85*			0	0.64ns	1.05ns
MD 3	**1.63**	*1.62*				0	0.41ns
CA	**2.05**	*1.62*					0
DRS 5							
CT	**2.55**	*1.05*	0	2.28ns	2.80ns	4.2ns	9.31*
MD 1	**4.83**	*2.60*		0	0.53ns	1.95ns	7.03*
MD 2	**5.35**	*2.67*			0	1.42ns	6.51ns
MD 3	**6.78**	*2.86*				0	5.08ns
CA	**11.86**	*7.42*					0
DRS 6							
CT	**0.39**	*0.11*	0	0.02ns	0.25ns	0.46ns	0.42ns
MD 1	**0.41**	*0.21*		0	0.23ns	0.44ns	0.40ns
MD 2	**0.64**	*0.38*			0	0.21ns	0.17ns
MD 3	**0.85**	*0.45*				0	0.04ns
CA	**0.81**	*0.29*					0
DRS 7							
CT	**0.01**	*0.02*	0	1.98ns	1.34ns	7.02*	6.87*
MD 1	**2.00**	*2.32*		0	0.64ns	5.03ns	4.89ns
MD 2	**1.35**	*1.19*			0	5.67ns	5.53ns
MD 3	**7.03**	*5.92*				0	0.14ns
CA	**6.88**	*4.73*					0

Note
Kg N ha^{-1}, mg L^{-1}, DRS, OA, ns, and *, represent kilogram ni-trogen per hectare, milli-gram per liter, Derived Sa-vanna, Organic amend- ment, not significant and significant at p <= 0.05 respectively.

Numbers in bold and italics are means of ru-noff nitrate and standard devia-tion of mean concentra-tion respectively.

DRS 1 to 3 are for dry season runoff while *DRS* 4 to 7 are for wet season runoff.

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Table 7
Pairwise Multiple Comparison of means of nitrate concentration of runoff under different urea treatments in the rain forest.

Urea rates Kg N ha^{-1}			0+OA	20+OA	40+OA	60+OA	80
			mg L^{-1}				
RFR 1							
CT	**3.29**	*1.13*	0	0.05ns	0.25ns	0.41ns	0.47ns
MD 1	**3.34**	*0.68*		0	0.29ns	0.45ns	0.52ns
MD 2	**3.05**	*1.45*			0	0.16ns	0.23ns
MD 3	**2.89**	*0.79*				0	0.07ns
CA	**2.82**	*0.76*					0
RFR 2							
CT	**4.95**	*1.69*	0	0.89ns	0.47ns	0.61ns	0.43ns
MD 1	**5.84**	*3.01*		0	1.37ns	1.51ns	0.46ns
MD 2	**4.47**	*1.76*			0	0.14ns	0.91ns
MD 3	**4.33**	*1.17*				0	1.05ns
CA	**5.38**	*2.51*					0
RFR 3							
CT	**1.80**	*0.73*	0	0.91*	1.31*	1.58*	1.42*
MD 1	**0.89**	*0.54*		0	0.39ns	0.21ns	0.42ns
MD 2	**0.49**	*0.36*			0	0.27ns	0.12ns
MD 3	**0.22**	*0.18*				0	0.16ns
CA	**0.38**	*0.56*					0
RFR 4							
CT	**0.87**	*0.84*	0	1.19ns	3.14*	1.75ns	1.69ns
MD 1	**2.05**	*0.91*		0	1.95ns	0.56ns	0.51ns
MD 2	**4.01**	*2.55*			0	1.40ns	1.45ns
MD 3	**2.61**	*2.10*				0	0.05ns
CA	**2.56**	*0.97*					0
RFR 5							
CT	**3.30**	*2.10*	0	11.60*	11.98*	13.88*	12.97*
MD 1	**14.90**	*4.34*		0	0.38ns	2.28ns	1.37ns
MD 2	**15.28**	*6.63*			0	1.89ns	0.99ns
MD 3	**17.18**	*3.58*				0	0.91ns
CA	**16.27**	*11.21*					0
RFR 6							
CT	**0.97**	*0.45*	0	0.80ns	1.43ns	1.43ns	2.41*
MD 1	**1.77**	*0.19*		0	0.63ns	0.63ns	1.62ns
MD 2	**2.40**	*0.69*			0	0.00ns	0.98ns
MD 3	**2.40**	*1.49*				0	0.99ns
CA	**3.38**	*1.90*					0
RFR 7							
CT	**2.48**	1.21	0	1.78ns	2.52ns	0.47	2.19ns
MD 1	**4.26**	2.46		0	0.74ns	2.25ns	0.41ns
MD 2	**5.00**	2.56			0	2.99ns	0.32ns
MD 3	**2.01**	0.88				0	2.66ns
CA	**4.67**	3.73					0

Note
Kg N ha^{-1}, mg L^{-1}, RFR, OA, ns, and *, represent kilogram nitrogen per hectare, milligram per liter, Rain Forest, Organic amend-ment, not significant and significant at p <= 0.05 respectively.

Numbers in bold and italics are means of nitrate concentration in runoff and standard deviation of mean con-centration respectively.

RFR 1 to 3 are for dry season runoff while *RFR* 4 to 7 are for wet season runoff.

ted in a similar study that the more the amount of urea applied, the higher the level of runoff contamination. Ruimin *et al.* (2013) in Xiangxi river watershed of China equally observed a proportional increase in various forms of runoff nitrogen with increase in chemical fertilizer. However, a common and pronounced observation in most of the runoff events in this study was that no differences existed between nitrate concentration in all the fertilizer treatments and control. This finding is supported by Easton and Petrovic (2004) who observed that even control with no fer-tilizer applied

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contributed as much or even higher level of N contamination as plots with nitrogen fertilizers, including urea. Crop uptake is also a significant path-way of nitrogen removal from soil. It was concluded that urea treatments enhanced the growth of dense canopy of plants in the plots and as a result favoured higher crop's nutrient uptake, lowered runoff (Easton and Petrovic, 2004) resulting in lower nutrient concentration in runoff. In the opposite, Miao *et al.* (2012) and Li *et al.* (2013) observed that few plant cover from farmlands enhanced sediment and nutrient loss. Horgan *et al.* (2002) indicated that losses from a combination of volatilization, denitrification, plant uptake and temporary soil storage could amount to about 61.4% of applied fertilizer. Hence, runoff nitrate losses observed in this study were probably not singly influenced by fertilizer rates and was not in direct proportion to amount of the applied fertilizer. The concentration of nitrate in each runoff event was far below the WHO, 2017 maximum allowable limit considered safe for human consumption. The level of fertilizer applied did not translate to any proportional change in the level of nitrate contamination of the runoff from the vegetable plots. This showed that all the fertilizer treatments investigated in this study are safe for the immediate farm environment. There is, however danger that aggregation of these nitrate contaminant level over large area of farmlands, downstream intensification of agricultural activeties and subsequent transfer of this contaminant over a watershed may lead to its significantly high concentration to make surface water bodies harmful for both human and animal consumption and to cause eutrophication (Bijay-Sing and Eric, 2021).

Effect of urea-N fertilizer on ammonium-nitrogen (NH_4–N) content of runoff

In Table 8 and 9, significant differences of runoff NH_4 –N concentration was mainly between the different urea treatments and control. At DRS 1, NH_4–N concentration was higher in each of MD 2, MD 3 and CA than in CT plots and at DRS 2, MD 3 plots had higher NH_4–N concentration than the control. Also at DRS 3, significantly higher amount of runoff NH_4–N was observed in CA plots compared to the control. At DRS 3, NH_4–N concentration in runoff were also higher in CA plots than MD 1 and MD 2 plots. In Table 9 (RFR 2 and 3), runoff from MD 2 plots also had higher NH_4–N concentration than the control. Similarly, the concentration of NH_4–N in runoff from MD 2 plots was more than what was observed in MD 1 plots at RFR 3. Furthermore, means difference between CA, MD 3 and the lower urea rates at RFR 4 indicated that the higher the fertilizer rate the more the ammonium contamination of the runoff. As observed in this study, significant pair-wise differences between means of runoff NH_4–N were only noticed in few instances. However, in those instances where the differences occurred, the quantity of urea applied was directly related to the concentration of NH_4–N in runoff. This was because NH_4–N being the immediate product of urea hydrolysis still represented the amount of urea applied as fertilizer and hence its tendency in runoff contamination. The high concentration of NH_4–N in runoff from plots in the two study locations may be due to the predominantly sandy texture of the soil. Sandy soils have low capacity to adsorb NH_4–N at exchange sites (Keller and Menegel, 1986). Apart from loss of NH_4–N in runoff from the plots, its presence in soil water is also a precursor to ammonia volatilization (Jones *et al.*, 2013). High concentration of NH_4–N in soil water results in high volume of ammonia to the environment. It was reported that NH_3 emissions through volatilization can account to as high as 50% of N loss and hence rated high on impact of agriculture on environment (Sadeghpour *et al.*, 2015, Brentrup *et al.*, 2001). At the time of nitrate and nitrites analyzes, some of the facilities for ammonium analyzes were unavoidably not available. Additionally, there were also some limitations of storage facilities. Hence, compared to runoff nitrates and nitrites, fewer runoff events could be analyzed for ammonium. Notably from previous studies however, nitrate (Bijay–Singh and Eric, 2021) and nitrite from fertilizer applications constitute an overwhelming challenge to both surface and ground water quality. This has made the focus on nitrate and nitrite nitrogen directly coming from field plots im-portant in this study. Further studies that will investi-gate all the species of nitrogen and their compounds in better details is envisaged. Additionally, the vast oc-currences of insignificant differences in NH_4–N con-centrations between the urea rates implied that all the fertilizer treatments had equal impact on the runoff water at the immediate plot environments. This sho-wed that in considering pollution tendency of the urea rates and control, all the treatments had the similar impact on runoff water from the plots. Corroborating this study, Easton and Petrovic (2004) equally re-ported that fertilizer treatment did not have any signi-fycant impact on runoff NH_4–N from a turf grass plot. Rather, they found out that water infiltration in-to the soil influenced the content of NH_4–N in runoff.

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Table 8
Pairwise Multiple Comparison of means of ammonium concentration in runoff under different urea treatments in derived savanna.

Urea rates Kg N ha^{-1}			CT	MD1	MD2	MD3	CA
			mg L^{-1}				
DRS 1							
CT	**0.38**	*0.05*	0	0.17ns	0.23*	0.38*	0.27*
MD 1	**0.21**	*0.17*		0	0.06ns	0.20ns	0.10ns
MD 2	**0.14**	*0.15*			0	0.14ns	0.04ns
MD 3	**0.00**	*0.00*				0	0.11ns
CA	**0.11**	*0.17*					0
DRS 2							
CT	**0.02**	*0.01*	0	0.10ns	0.36ns	0.38*	0.30ns
MD 1	**0.12**	*0.02*		0	0.25ns	0.10ns	0.04ns
MD 2	**0.37**	*0.32*			0	0.10ns	0.04ns
MD 3	**0.46**	*0.33*				0	0.14ns
CA	**0.33**	*0.23*					0
DRS 3							
CT	**0.17**	*0.10*	0		4.26ns	6.60ns	13.70*
MD 1	**2.99**	*1.70*		3.31ns	0.95ns	3.28ns	13.38*
MD 2	**4.43**	*1.67*		0	0	2.33ns	12.43*
MD 3	**10.78**	*1.94*				0	10.10ns
CA	**11.06**	*11.00*					0

Note
Kg N ha^{-1}, mg L^{-1}, DRS, OA, ns, and *, represent kilogram nitrogen per hectare, mil-ligram per liter, Derived Savanna, Organic amendment, not signi-ficant and significant at p <= 0.05 respectively. Num-bers in bold and italics are means of runoff ammo-nium and standard deviation of mean concentration re-spectively. *DRS* 1 is for dry season runoff while *DRS* 3 and 4 are for wet season runoff.

Table 9
Pairwise Multiple Comparison of means of ammonium concentration in runoff under different urea treat-ments in rain forest.

Urea rates Kg N ha^{-1}			CT	MD1	MD2	MD3	CA
			mg L^{-1}				
RFR 1							
CT	**1.12**	*0.79*	0	3.45ns	3.84*	2.28ns	3.20ns
MD 1	**4.57**	*3.15*		0	0.40ns	1.18ns	0.26ns
MD 2	**4.96**	*2.22*			0	1.57ns	0.66ns
MD 3	**3.39**	*1.18*				0	0.92ns
CA	**4.31**	*2.78*					0
RFR 2							
CT	**0.02**	*0.01*	0	0.08ns	0.39*	0.31ns	0.17ns
MD 1	**0.10**	*0.07*		0	0.30ns	0.23ns	0.09ns
MD 2	**0.40**	*0.31*			0	0.19ns	0.21ns
MD 3	**0.33**	*0.21*				0	0.14ns
CA	**0.19**	*0.21*					0
RFR 3							
CT	**0.00**	*0.00*	0	0.21ns	1.55*	0.81ns	1.53*
MD 1	**0.21**	*0.30*		0	1.34*	1.05ns	1.32*
MD 2	**1.55**	*1.34*			0	0.75ns	0.02ns
MD 3	**0.81**	*1.37*				0	0.73ns
CA	**1.53**	*0.44*					0
RFR 4							
CT	**0.65**	*0.30*	0	0.35ns	1.26ns	5.40*	16.47*
MD 1	**1.00**	*0.87*		0	0.91ns	5.05*	16.12*
MD 2	**1.91**	*0.66*			0	4.14*	15.21*
MD 3	**6.05**	*3.53*				0	11.07*
CA	**17.12**	*4.19*					0

Note
Kg N ha^{-1}, mg L^{-1}, RFR, OA, ns, and *, represent kilogram nitrogen per hectare, milligram per liter, Rain Forest, Organic amendment not signifycant and significant at p <= 0.05 respectively.

Numbers in bold and italics are means of runoff ammo-nium and standard deviation of mean concentration re-spectively.

RFR 1 and 2 are for dry season runoff while *RFR* 3 and 4 are for wet season runoff.

Effect of urea–N fertilizer on nitrate concentration of sediment

In Table 10, the mean difference at *DRS* 2 indicated that sediment from CA plots had significantly higher ni-
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nitrate concentration than other urea rates. On the contrary, sediment from MD 1 and MD 2 plots (Table 11) accumulated more nitrate than those from higher fertilizer rates and control at RFR 2. This result

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showed that except in the reported few cases (33.3% in derived savanna and 14.3% in rainforest), the nitrate contents of sediments from most of the runoff events were significantly affected by the fertilizer treatments.
This pattern was equally observed on impact of the fertilizer rates on runoff nitrate content, thus suggesting that the sediment nitrate content was a reflection of runoff content of the nitrogen specie. A possible reason for this observation could be linked to urea conversion after its application. However, nitrate contents of the runoff sediments was higher than of the runoff. The finding of MaClean and McRae (1987) showed that it took 70 days for 95.4% of the applied urea to be con-verted to nitrate in the soil (soil temperature = 20.8°C). Although their study showed that the rate of urea conversion increased with increase in temperature, and that average soil temperature during this study was 37°c, significant amount of the applied urea may not had been converted to nitrate at the time of runoff and sediment collection. Motasim *et al.* (2021) also observed in an incubation study that it took about 14 days for most of the urea applied to be mineralized into nitrates. In this study, a different approach involving runoff data collection on the day of fertilizer application, and the successive days after rainfall or irrigation may be substantial on the nitrate in the sediments. Leaching and volatilization are another means through which the fertilizer could have been lost. However, larger amounts of nitrates were contained in soil sediments compared to nitrate nitrogen in runoff. It showed that irrespective of the urea rates applied, nitrate turn over in sediments to the immediate farm environment could be dangerous if it eventually found its way to water bodies after continuous rainfall and irrigation events.

Conclusions

The study investigated the impact of urea fertilizer on the concentration of NO_2–N, NO_3–N and NH_4–N in runoff as well as sediment nitrate nitrogen from vegetable plots. In conclusion, the urea rates applied did not result in cummensurate increase on the height of eggplant. The concentration of NH_4–N in runoff from fertilized plots under *Solannum macrcarpon* increased with rate of urea applied but other forms of nitrogen (NO_3–N and NO_2–N) in runoff and sediment were not different with quantity of the fertilizer applied. Based on allowable limits from regulatory authority, WHO, only NO_2–N from CA in derived savanna was deemed hazardous while in rainforest, nitrite from all plots could be harmful to human health if it found its way to drinking water bodies. However, NO_3–N nitrogen released from the plots posed no risk to the immediate farm environment.

Conflict of interests

The authors declare no conflict of interest

Table 10
Pairwise multiple comparison of means of nitrate concentration of sediment under different urea treatments in the derived savanna.

Urea rates Kg N ha^{-1}			CT	MD1	MD2	MD3	CA
			mg L^{-1}				
DRS 1							
CT	**3.56**	*16.44*	0	8.60ns	5.37ns	11.15ns	8.09ns
MD 1	**4.96**	*12.22*		0	3.23ns	2.55ns	0.50ns
MD 2	**8.18**	*26.44*			0	5.78ns	2.72ns
MD 3	**2.41**	*5.49*				0	3.06ns
CA	**15.47**	*4.07*					0
DRS 2							
CT	**3.26**	*3.04*	0	1.32ns	2.01ns	2.53ns	18.56*
MD 1	**1.94**	*0.96*		0	0.69ns	3.85ns	19.88*
MD 2	**1.24**	*0.07*			0	4.54ns	20.57*
MD 3	**5.79**	*2.67*				0	16.03*
CA	**1.82**	*14.10*					0
DRS 3							
CT	**7.67**	*37.93*	0	5.54ns	9.33ns	26.06ns	18.76ns
MD 1	**2.13**	*45.04*		0	3.79ns	51.60ns	44.30ns
MD 2	**8.34**	*37.66*			0	55.39ns	48.09ns
MD 3	**3.73**	*20.96*				0	7.3ns
CA	**6.43**	*50.96*					0

Note
Kg N ha^{-1}, mg L^{-1}, RFR, OA, ns, and *, represent kilogram nitrogen per hectare, milligram per li-ter, Derived Savanna, Organic amendment, not signify-cant and significant at p <= 0.05 respectively. Numbers in bold and italics are means of sediment nitrate and standard deviation of mean concentration respectively. *DRS* 1 is for dry season sediment while *DRS* 3 and 4 are for wet season runoff.

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Table 11
Pairwise Multiple Comparison of means of nitrate concentration of sediment under different urea treatments in the rain forest.

	Urea rates Kg N ha^{-1}		CT	MD1	MD2	MD3	CA
			mg L^{-1}				
RFR 1							
CT	**24.01**	*23.86*	0	19.74ns	20.12ns	5.31ns	19.02ns
MD 1	**3.75**	*23.88*		0	0.38ns	14.43ns	38.76*
MD 2	**44.13**	*36.87*			0	14.82ns	39.14*
MD 3	**9.32**	*24.32*				0	24.33ns
CA	**4.99**	*3.85*					0
RFR 2							
CT	**25.39**	-	0	3.39ns	18.95ns	30.87ns	45.92ns
MD 1	**71.78**	*12.88*		0	27.44ns	15.52ns	0.47ns
MD 2	**4.34**	*23.12*			0	11.93ns	26.98ns
MD 3	**6.26**	*45.48*				0	15.05ns
CA	**71.31**	*37.45*					0
RFR 3							
CT	**2.34**	*3.04*	0	15.58	3.67	16.04	20.18
MD 1	**6.76**	*0.96*		0	11.91ns	0.46ns	4.60ns
MD 2	**8.67**	*0.07*			0	12.37ns	16.51ns
MD 3	**6.30**	*2.67*				0	4.15ns
CA	**22.15**	*14.10*					0
RFR 4							
CT	**0.66**	*1.16*	0	0.48ns	0.46ns	3.15ns	0.91
MD 1	**1.14**	*1.79*		0	0.94ns	2.66ns	0.42ns
MD 2	**0.20**	*0.13*			0	3.60ns	1.36ns
MD 3	**3.80**	*5.23*				0	2.24ns
CA	**1.56**	*2.00*					0
RFR 5							
CT	**3.18**	*5.16*	0	3.18ns	3.11ns	2.29ns	2.49ns
MD 1	**0.00**	*0.00*		0	0.07ns	0.89ns	0.69ns
MD 2	**0.07**	*0.07*			0	0.82ns	0.62ns
MD 3	**0.89**	*1.78*				0	0.20ns
CA	**0.69**	*1.07*					0
RFR 6							
CT	**3.81**	*7.04*	0	0.43ns	0.85ns	0.17ns	9.21ns
MD 1	**4.24**	*7.02*		0	0.42ns	0.27ns	8.77ns
MD 2	**10.66**	*10.39*			0	6.69ns	2.36ns
MD 3	**3.97**	*7.19*				0	9.04ns
CA	**13.01**	*10.34*					0

Note
Kg N ha^{-1}, mg L^{-1}, RFR, OA, ns, and *, represent kilogram nitrogen per hectare, milligram per liter, Rain Forest, Organic amendment, not significant and significant at p <= 0.05 respectively.

Numbers in bold and italics are means of sediment nitrate and standard deviation of mean concentration respectively.

RFR 1 to 3 are for dry season sediment while *RFR* 4 to 6 are for wet season sediment.

References

ABEGUNRIN T.P, AWE G.O., SANGODOYIN A.Y., ONOFUA O.E., OGUNTOYE O.M. (2017) Impacts of Storage duration and materials on the quality of rainwater in Ogbomoso, Southwest Nigeria. International Journal of Current Microbiology and Applied Sciences 6(7): 4489-4500. https://doi.org/10.20546/ijcmas.2017.607.468

AL-KANANI T., MACKENZIE A. F., BARHAKUR N. N. (1991) Soil water and ammonia volatilization rela-tionships with surface-applied nitrogen fertilizer solutions. Soil Science Society of America Journal 55:1761-1766. http://dx.doi.org/10.2136/sssaj1991.03615995005500060043x

BARROS T., BOSCOV L., BATISTELLA F. PESSÔA DA CRUZB M. FERREIRA M.(2019) Mineral nitrogen fertilization effects on lettuce crop yield and nitrogen leaching. Sci. Hortic., 255:153–160. https://doi.org/10.1016/j.scienta.2019.05.032

BIJAY- SINGH, ERIC C. (2021) Fertilizers and Nitrate Pollution of surface water: An increasingly pervasive global. Springer Nature Journal of Applied sciences, 3:518. https://doi.org/10.1007/s42452 021-04521-8

BØRGESEN C., PULLENS J., ZHAO J.,BLICHER-MATHIESEN G., SØRENSEN P. OLESEN J. (2022) An empirical model for estimating nitrate leaching from the root zone of agricultural land. European Journal of Agronomy 134 :126465. . https://doi.org/10.1016/j.eja.2022.126465

DOI: 10.6092/issn.2281-4485/20387

BRENTRUP F., KÜSTERS J., KUHLMANN H., LAMMEL J. (2001). Application of the life cycle assessment methodology to agricultural production: An example of sugar beet production with different forms of nitrogen fertilizers. European Journal of Agronomy, 14:221–233. https://doi.org/10.1016/S1161-0301(00)00098-8

BREWER P.G., RILEY J.P. (1965) The automatic determination of nitrate in sea water: Deep Sea Research 12:765-772. https://doi.org/10.1016/0011-7471(65)90797-7

DIAS J. (2012). Nutritional quality and health benefits of vegetables: A Review. Food and Nutrition Sciences, 10(3): 1354-1374. https://doi.org/10.4236/fns.2012.310179

EASTON Z.M., PETROVIC, A.M. (2004) Fertilizer source effect on ground and surface water quality in drainage from turfgrass. Journal of Environmental Quality 33:645-655. https://doi.org/10.2134/jeq2004.6450

ERNST J.W., MASSEY H.F. (1960) The effects of several factors on volatilization of ammonia formed from urea in the soil. Soil Science Society of America Proceedings 24:87-90. https://doi./10.2136/sssaj1960.03615995002400020007

ESPEJO-HERRERA N., GRÀCIA-LAVEDAN E., BOLDO E., ARAGONÉS N., PÉREZ-GÓMEZ B., POLLÁN M., MOLINA A.J., FERNÁNDEZ T., MARTÍN V., LA VECCHIA C. (2016) Colorectal cancer risk and nitrate exposure through drinking water and diet. International Journal of Cancer, 139:334–346. doi:10.1002/ijc.30083.

FANG Q.X., MALONE R.W., MA L., JAYNES D.B., GREEN T.R., AHUJA L.R. (2012) Modeling controlled tile flow, nitrogen application rate, and weather effects on nitrogen loss to streams. Agricultural Water Management 103:150–161. https://doi.org/10.1016/j.agwat.2011.11.006

FOOD AND AGRICULTURAL ORGANIZATION CORPORATE DATABASE. (2020) Free Database for Food and Agricultural Organization of the United Nations, FAOSTAT. https://www.faoatat.org.

FISCHER G., WINIWARTER W., ERMOLIEVA T., CAO G.Y., QUI H., KLIMONT Z. WIBERG D., WAGNER F. (2010). Integrating Modelling framework for assessment and mitigation of nitrogen pollution from agriculture: Concept and case study for China. Agriculture, Ecosystems and Environment 136: 116–124. https://doi.org/10.1016/J.AGEE.2009.12.004

GALLOWAY J.N., ABER J.D. ERISMAN J.W., SEIZINGER S.P., HOWARTH, R.W., COWLING E.B. COSBY, B.J. (2003) The nitrogen cascade. BioScience 53, 341-356. https://doi.org/10.1641/0006-3568(2003)053[0341:TNC]2.0.CO2

GOOLSBY D.A., BATTAGLIN W.A. (2000). Nitrogen in the Mississippi basin estimating sources and flux to the Gulf of Mexico. USGS Fact Sheet 135-00. https://ks.water.usgs.gov/Kansas/pubs/fact-sheets/fs.35-00.pdf

HORGAN B.P., BRANHAM B.E. AND MULVANEY R. L. (2002). Mass balance of 15N applied to Kentucky bluegrass including direct measurement of denitrification. Crop Sciences, 1595. https://doi.org/10.2135

HOUBA V.J.G., TEMMINGHOFF E.J.M., GAIKHORST G.A., VAN VARK W. (2000). Soil analysis procedure using 0.01M Calcium Chloride as extracting agent. Communications in Soil Science and Plant Analysis 31(9-10): 1299-1396. . http://dx.doi.org/10.1080/00103620009370514

HUANG Y., ZHANG Z., LI, Z., DAI D., LI Y.(2022). Evaluation of water use efficiency and optimal irrigation quantity of spring maize in Hetao Irrigation District using the Noah-MP Land Surface Model. Agricultural Water Management, 264. .https://doi.org/10.1016/j.agwat.2022.107498.

IQBAL T. (2006). Study on vertical and lateral leaching of nitrate from a wheat om a wheat field in China. Turkish Journal of Agriculture and Forestry30:59-65.

JABBAR F. K, GROTE K. (2019). Statistical assessment of nonpoint source pollution in agricultural watersheds in the Lower Grand River watershed, MO, USA. Environmental Science Pollution Research 26, 1487–1506. https://link.springer.com/article/10.1007/s11356-018-3682-7

JONES C., BROWN B. D., ENGEL R., HORNECK D., OLSON-RUTZ K. (2013). Factors affecting nitrogen fertilizer volatilization. Montanna State University Extension Bulletin 2013, 1-6.

KELLER G.D., D. B. MENGEL. (1986). Ammonia volatilization from nitrogen fertilizers surface applied to no-till corn. Soil Science Society of America Journal. 50, 1060-1063.

LI X.S. WU B.F., ZHANG L. (2013) Dynamic monitoring of soil erosion for upper stream of Miyun reservoir in the last 30 years. Journal of Institution of Water and Environmental Management 5, 460-465.

LIU J., YOU, L., AMINI M., OBERSTEINER M., HERRERO M., ZEHNDER A.J.B. YANG H. (2010) A resolution assessment of global nitrogen flows in cropland. Proceedings of National Academy of Science, USA 107:8035-8040. https://doi.org/10.1073/pnas.0913658107

LIU Y., JIANG D.S., LI Y.J., ZHANG, R.F., LI, M. CUI, Y.B. (2014) Influence of environmental factors on the acute toxicity of ammonia to corbicula fluminea and limnodrilus hoffmeisteri. Research Environmental Sciences 27(9), 1067-1073. https://doi.org/10.13198/j.issn.1001.6929.2014.09.16

LONGNECKER M.P. DANIELS J. L. (2001) Environmental contaminants as etiologic factors for diabetes. Environmental Health Perspectives 109, 871-876. https://doi.org/10.1289/ehp.01109s6871

DOI: 10.6092/issn.2281-4485/20387

MA B., GUAN R., LIU L., HUANG Z., QI S., XI Z., ZHAO Y., SONG S. YANG H. (2021) Nitrogen loss in vegetable field under the simulated rainfall experiments in Hebei China. Water 13:552. https://doi.org/10.3390/w13040 552

MACLEAN, A.A. MCRAE, K.B. (1987). Rate of hydrolysis and nitrification of urea and implication of its use in potato production. Canadian Journal of Soil Science 67:679-686. https://doi.org/10.4141/cjss87-064

MCSWINEY, C. P., ROBERTSON, G. P. (2005). Nonlinear response of N_2O flux to incremental fertilizer addition in a continuous maize (Zea mays L.) cropping system. Global Change Biology 11:1712–1719. https://doi.org/10.1111/j.1365-2486.2005.01040.x

MIAO C. Y., YANG L. CHEN X. H. (2012). The vegetation cover dynamics (1982-2006) in different erosion regions of the Yellow River basin, China. Land Degradation and Development 23:: 62-71. http://dx.doi.org/10.1002/ldr.1050

MINISTRY OF ENVIRONMENT AND FOOD OF DENMARK MINISTERIAL ORDER ON WATER QUALITY AND MONITORING OF WATER SUPPLY PLANTS. (2017) Water Supply Act, 125:.1978-06-08 . https://doi.org/10.34194/geusb.v49.8319

MITCHELL C., BRODIE J., WHITE I. (2005). Sediments, nutrients and pesticide residues in event flow conditions in streams of the Mackay Whitsunday Region, Australia. Marine Pollution Bulletin 51: 23–36. https://doi.org/10.1016/j.marpolbul.2004.10.036

MOTASIM A.M., SAMSURI A.W., ABDULSUKOR A. S., ADIBAH A.M. (2021). Nitrogen dynamics in tropical soils treated with liquid and granular urea fertilizers. Agriculture, 11:546. https://doi.org/ 0.3390/agriculture11060546

OKOYA A.A., OSUNGBEMIRO B.W., OLOGUNORISA T.E. (2017). Spatial and Temporal Variation of Rainwater Chemistry in Ile-Ife and Its Environ, Osun State, Nigeria. Journal of Sustainable Development 10(2). https://doi.org/10.5539/jsd.v10n2p203

OLASOJI H.O., OJETADE J.O., MUDA S.A. AMUSAN A.A. (2022). Characterisation, classification and suitability assessment of soils formed in granite and gneiss in humid area of southwestern Nigeria for cacao (Theobroma cacao) production. Tropical Agriculture 99, 11 – 26. ISSN (Print): 0041-3216

OLSON K.R., AL-KAISI M., LAL R., CIHACEK L. (2016). Impact of soil erosion on soil carbon stocks. Journal of Soil and Water Conservation 71(3): 62A-67A. https://doi.org/10.2489/jswc.71.3.61A

STATE GOVERNMENT (2012). Waste to wealth. Ondo State Waste Management Bulletin on the use of Organic Fertilizer and Organomineral Fertilizer, Ondo State, Nigeria, pp: 10.

POWERS S.E. (2007). Nutrients loads to surface water from row crop production. International Journal of Life Cycle Assessment 12(6): 399-407. http://dx.doi.org/10.1007/s11367-007-0307-7

RUIMIN L., PEIPEI Z., XIUJUAN W., YAXIN C. ZHENYAO S. (2013). Assessment of effects ofbest management practices on agricultural non-point source pollution in Xiangxi River watershed. Agricultural Water Management 117: 9–18. https://doi.org/10.1016/j.agwat.2012.10.018

SADEGHPOUR A., HASHEMI M., WEIS S.A., SPARGO, J.T., MEHRVARZ S., HERBERT S.J. (2015). Assessing tillage systems for reducing ammonia volatilization from spring-applied slurry manure. Communication in Soil Science and Plant Analysis 46: 724–735. https://doi.org/10.1080/00103624.2015.1005223

SHETTY P., ACHARYA C. VEERESH N. (2019). Effect of urea fertilizer on the biochemical characteristics of soil. International Journal of Applied Sciences and Biotechnology 7(4): 414-420. http://dx.doi.org/10.3126/ijasbt.v7i4.26778

SOIL SURVEY STAFF (2014). Keys to soil taxonomy. 12th ed. USDA Natural Resources Conservation Service.

SMITH, D. R., KING K. W., JOHNSON L., FRANCESCONI W., RICHARD P., BAKER D., SHARPLEY A.N. (2015). Surface runoff and tile drainage transport of phosphorus in mid- western United States. Journal of Environmental Quality 44::495- 502. .https://doi.org/10.2134/jeq2014.04.0176

STARK C. RICHARDS K. (2008). The continuing challenge of agricultural nitrogen loss to the environment in the context of global climate change and advancing research. Dynamic Soil, Dynamic Plant 2(1), 1-12.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, USEPA, (2003) Introduction to the clean water act. Online at http://www.epa.go/watertrain/cwa/

VILLANUEVA C.M., KOGEVINAS M., CORDIER S., TEMPLETON M.R., VERMEULEN R., NUCKOLS J.R., NIEUWENHUIJSEN M.J., LEVALLOIS P. (2014) Assessing exposure and health consequences of chemicals in drinking water: Current State of Knowledge and Research Needs. Review. Environental Health Perspectives 122:213–221. https://doi.org/10.1289/ehp.1206229

WALLMAN M DELIN S (2022). Nitrogen leaching from tile – drained fields and lysemeters receiving rates and sources of nitrogen. Soil Use and management 38(1):596 – 610. https://doi.org/10.1111/sum.12724

WORLD HEALTH ORGANIZATION (2017). Guidelines for drinking water quality (4th ed. incorporating first addendum), http://www.who.int/water_sanitation_health/publications/dwq-guidelines-4/en..

DOI: 10.6092/issn.2281-4485/20387

WORLD HEALTH ORGANIZATION (2011). Guidelines for drinking water quality (4th ed. pp. 398-403), WHO. ISBN: 9789241548151

XIA Y., ZHANG M., TSANG D. C. W., GENG N., LU D., ZHU L., IGALAVITHANA A. D., DISSANAYAKE P. D., RINKLEBE J., YANG X., YONG S. O. (2020) Recent advances in control technologies for non-point source pollution with nitrogen and phosphorous from agricultural runoff: current practices and future prospects. Applied Biological Chemistry 63:8. https://doi.org/10.1186/s13765-020-0493-6

ZHANG T.Q., TAN C.S., ZHENG Z.M., DRURY C.F. (2015) Tile drainage phosphorus loss With long-term consistent cropping systems and fertilization. Journal of Environmental Quality 44, 503 – 511. DOI: 10.2134/jeq2014.04.0188

ZHAO X., ZHOU Y., MIN J., WANG, S, SHI W.,XING G. (2012) Nitrogen runoff dominates water nitrogen pollution from rice-wheat rotation in the Taihu Lake region of China. Agriculture, Ecosystems and Environment 156:1–11. http://dx.doi.org/10.1016/j.agee.2012.04.024