



ORIGINAL RESEARCH ARTICLE

EFFECT OF RAINFALL AND FERTILIZER APPLICATION TIMING ON NUTRIENT EXPORTS FROM A MAIZE FIELD

M. Ogunremi¹, T. P. Abegunrin², A. Akintola¹ and I. A. Abdulsalam³

¹Department of Agricultural Engineering Oyo State college of Agricultural technology, Igbo-Ora.

²Department of Agricultural Engineering, Ladoke Akintola University of Technology, Ogbomosho.

³Department of Agricultural Engineering, Osun State University, Osogbo.

*Corresponding author's email: ogunremi02@gmail.com

ARTICLE INFORMATION

Received: 14th April 2025

Revised: 1st May 2025

Accepted: 2nd May 2025

Keywords:

Nutrient export

Sediment

Fertilizer application

Nutrient availability

ABSTRACT

Nutrient losses from agricultural fields are significantly influenced by fertilizer management practices and rainfall patterns. Gaining insight into these effects supports the development of effective mitigation strategies. This study investigated the effect of rainfall and fertilizer application timing on nutrient export from a maize field. Daily rainfall data were obtained from Ogun-Osun River Basin Development Authority (OORBDA) meteorological station at Igboora. The field experiment included early, split, and late single fertilizer application treatments, specifically assessing their impact on nitrate loss. Runoff from each treatment plot was collected using plastic gutters leading to wooden tanks. Samples were manually drawn at the onset, midpoint, and conclusion of each runoff event, provided rainfall exceeded 10 mm. Runoff samples were analyzed for sediment concentration using gravimetric techniques, while nitrate, ammonium, total dissolved nitrogen, and total dissolved phosphorus were measured using standard colorimetric methods. Rainfall events ranged from 29.7 mm to 393.8 mm. The analysis revealed that nitrate concentrations in runoff averaged 35.3 ± 20.55 mg/L, ranging from 5.67 to 78.41 mg/L. Early fertilizer application resulted in an increased average nitrate concentration of 41.4 mg/L. In terms of sediment-bound nutrients, particulate phosphorus concentrations averaged 10.09 ± 7.17 µg/g, with values between 0.37 and 24.09 µg/g. Particulate nitrogen concentrations averaged 13.15 ± 7.87 µg/g, ranging from 3.07 to 31.04 µg/g. Also, it was observed that fertilizer treatments led to an increase in particulate phosphorus concentrations, averaging 10.83 µg/g after the initial application. The observed influence of rainfall and fertilizer timing on multiple nutrient pathways highlights the need for integrated nutrient management strategies, especially in tropical agro-ecosystems.

© 2025 Faculty of Engineering, University of Maiduguri, Nigeria. All rights reserved.

1.0 Introduction

In recent decades, the use of inorganic fertilizers in agriculture has significantly increased, largely driven by the rising global demand for food and fibre to sustain an ever-growing population (Harindintwali et al., 2021). However, in many developing countries such as Nigeria, soil fertility testing remains inadequate, leading to highly indiscriminate fertilizer application (Abdulraheem et al., 2022). The quantity of fertilizer used often exceeds the actual nutrient requirements of the crops. This mismatch results in a considerable portion of the applied nutrients becoming susceptible to loss through surface runoff and soil erosion (Rashmi et al., 2022). Moreover, the timing of fertilizer application plays a critical role in determining nutrient uptake efficiency. Applying fertilizer during periods of intense rainfall or when crops have low nutrient demands substantially increases the risk of nutrient losses, thereby reducing fertilizer use efficiency and contributing to environmental degradation (Li et al., 2020). Runoff from agricultural land acts as a major transport mechanism for both sediments and nutrients—both in dissolved and particulate forms—into adjacent surface water bodies. The consequences of such transport are far-reaching and include the reduction of reservoir storage capacities, degradation of water quality, oxygen depletion (hypoxia), proliferation of harmful algal blooms, and eutrophication (Li et al., 2020). These environmental challenges are especially severe in Nigeria, notably in

Corresponding author's email address: ogunremi02@gmail.com

areas such as the confluence of Rivers Niger and Benue, and around Ogun and Osun Rivers. These surface water bodies in these areas have suffered substantial reductions in storage capacity and are heavily infested with aquatic weeds and have exhibited significant declines in aquatic biodiversity (Omokaro *et al.*, 2014). The predominant sources of environmental challenges are sediment and nutrient exports from intensively cultivated farmlands. To develop effective strategies for mitigating these adverse effects, it is crucial to understand both the contributing factors and the underlying mechanisms that drive nutrient and sediment transport from agricultural fields into water systems.

In particular, the timing of fertilizer application and the influence of rainfall events play critical roles in the mobilization and transport of sediment and nutrients from agricultural fields into surface water bodies (Khan *et al.*, 2018). Variability in soil properties has long been recognized especially in tropical soils due to variations in macro and micro flora and fauna (Sanchez *et al.*, 2011; Orimoloye *et al.*, 2018). The timing of fertilizer application in maize cultivation significantly influences nutrient runoff, especially under varying rainfall conditions. Some researches conducted by Wang *et al.*, (2025), Davies *et al.*, (2020), and Abebe and Feyisa, (2017) indicates that synchronizing nitrogen (N) fertilizer application with maize's growth stages can enhance nitrogen use efficiency (NUE) and reduce environmental losses. Waring *et al.* (2022) examined the effects of Nitrogen fertilizer timing on nitrate loss and crop production in northwest Iowa. Their findings revealed that spring-applied anhydrous ammonia (AA) reduced annual nitrate concentrations in leachate compared to fall applications. Additionally, splitting fertilizer applications between pre-plant and sidedress stages, based on soil nitrate concentrations, showed potential in decreasing N losses while boosting grain yields. However, study has emphasized the necessity for site-specific evaluations due to variations in soil moisture, temperature, and microbial activity, which influence N cycling and soil mineralization rates (Fujita *et al.*, 2013). Hence, this study investigates the effects of rainfall intensity and fertilizer timing on nutrient export from a maize cultivation field located in Igboora, Oyo State, Nigeria.

2. Materials and Methods

2.1 Study Area

This study was conducted in Igboora, located in the southwestern region of Nigeria. Igboora is located on the geographic coordinates of 7.4368°N and 3.2885°E. The town is situated approximately 66 km northwest of Ibadan, the capital of Oyo State, and about 32 km north of Abeokuta, the capital of Ogun State (Figure 1). The area lies within the tropical climatic zone characterized by distinct wet and dry seasons. The region experiences a bimodal rainfall distribution, with peak precipitation periods occurring in May/June and September/October. Mean annual rainfall ranges between 1,190 mm and 1,342 mm, while the mean daily maximum and minimum temperatures are approximately 32 °C and 21 °C, respectively (IITA, 2008). It falls within Agro-Ecological Zone N (Oyo–Ibadan–Ondo–Oka Plains), which is classified as very humid (Orimoloye *et al.*, 2018). The topography of the study area is generally low, with elevations ranging between approximately 110 and 280 meters above sea level, and is categorized under the Guinea slope of the Niger–Guinea watershed. The experimental farm is located on the outskirts of Igboora, specifically at Asako Farm Settlement. A stream flows along the boundary of the farm, linking directly to the Ofiki River, which forms part of the Ogun–Osun River Basin. The farm site is characterized by slightly to moderately undulating terrain and underlain by crystalline basement complex rocks.

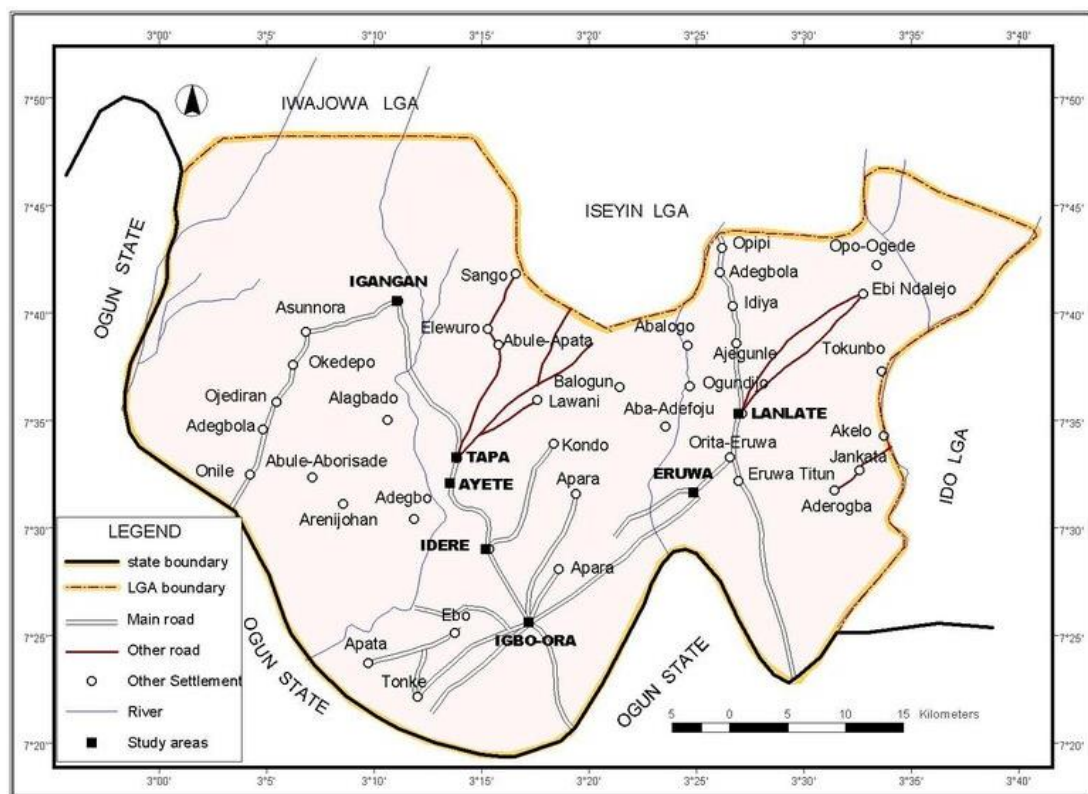


Figure 1: Map of Ibarapa Central Local Government, Oyo State showing the study location (Ogundele and Owoade, 2016)

2.2 Procedure for Data Collection

2.2.1 Collection of rainfall data

The daily rainfall data of the study area during the study period was collected from Ogun-Osun River Basin Development Authority (OORBDA) rain gauge station at Igboora. The rainfall data were used to assess the relationship between rainfall amount and nutrient export from the study area.

2.2.2 Land preparation, planting and fertilizer application

The experimental field used for the study was ploughed twice. Maize seeds (*Oba super 26 yellow*) was planted at a spacing of 25 cm within row and 75 cm between rows with two stands per hole. This translated to a population of 106,667 stands of maize. Basal fertilizer (NPK 20:10:10) was applied at the rate of 125 kg ha⁻¹ two weeks after planting as first dose, while the second dose, urea (46% Nitrogen) was applied at the rate of 100 kg ha⁻¹ at the onset of the tasselling. All these procedures are in conformity to the farmers' usual practices.

2.2.3 Runoff sample collection

Runoff samples were collected, using manual samplers, at the beginning, during and immediately after all rainfall events that occurred in the day during the study period. Runoff samples in the night were not collected due to the unavailability of automatic runoff samplers.

2.3 Laboratory Analysis

2.3.1 Determination of particulate nitrogen and phosphorus concentrations

The procedures described in Li *et al.* (2020) were used to determine the concentrations of sediment, nitrogen (N) and phosphorus (P) in the runoff samples. The suspended sediment (water-sediment mixture sample) in 1 L bottle was filtered using Whatman Grade 602 h (0.45-μm) filter paper. For the determination of concentrations of sediment, particulate N and particulate P, the sediment on filter paper were oven-dried at 40 °C for 1 hour, weighed and subsampled. Another subsample of the sediment was further oven-dried at 105 °C for 1 hour to a constant mass for the estimation of sediment concentration in the surface runoff. Sediment concentration was calculated according to Equation 1 (Li *et al.*, 2020).

$$S_{ci} = \frac{S_i}{1 L} \quad 1$$

where S_{ci} is the sediment concentration (g L^{-1}) and S_i is the dry mass (g) of the sediment in water-sediment mixture in 1 L sample.

Sediment loss rate (S_L , t ha^{-1}) in a single rainfall event was obtained using following Equation 2.

$$S_L = \sum_{i=1}^n \frac{S_{ci} * V_i * T_i}{A_x * 10^3} \quad 2$$

Where n is the total number of samples, i is the individual sample per rainfall event, V_i is the runoff volume at different sampling periods ($\text{m}^3 \text{hr}^{-1}$), T_i is the sampling interval time of different samples (hr), and A_x is the sub-watershed area (ha).

The subsample of the sediment was dried at 40°C and then gently crushed, allowed to pass through a 0.2 mm sieve, and thereafter analyzed for particulate N and P using standard methods. The particulate N (PN) concentration (g kg^{-1}) in the sediment were determined following method described in Are *et al.* (2022), while the particulate P (PP) concentration (g kg^{-1}) was determined calorimetrically using hot perchloric acid digestion (Rahutomo *et al.*, 2018). The PN and PP losses (kg ha^{-1}) in each rainfall event were calculated as follow in Equation 3 (Li *et al.*, 2020).

$$PN_L \text{ or } PP_L = \sum_{i=1}^n \frac{S_{ci} * V_i * T_i * PN_i / PP_i}{A_x} \quad 3$$

where, $PN_L \text{ or } PP_L$ is the particulate N or P loss, PN_i / PP_i is the concentration of PN or PP in the sediment for each rainfall event.

2.3.2 Determination of dissolved nitrogen and phosphorus concentration

The procedure described by Li *et al.* (2020) was used for the determination of dissolved nutrients; Total Dissolved Nitrogen (TDN), Ammonium Nitrogen ($\text{NH}_4^+\text{-N}$), Nitrate Nitrogen ($\text{NO}_3\text{-N}$) and Total Dissolved phosphorus (TDP). The Total Dissolved Nitrogen (TDN) was determined by potassium persulfate digestion UV spectrophotometry (GB1894-89) method; ammonium nitrogen ($\text{NH}_4\text{-N}$) by using Nessler's reagent colorimetric method (HJ 535-2019); nitrate nitrogen ($\text{NO}_3\text{-N}$) by ion chromatography (HJ 84- 2016) and TDP by the molybdenum blue method (GB1893-89). The reactions were analysed using Beckman DU640 UV-Vis spectrophotometer. Runoff depth was calculated using Equation 4 (Li *et al.*, 2020).

$$R_o = \frac{Q_i * T_i}{10^7 * A_x} \quad 4$$

where R_o is the runoff (mm), Q_i is the discharge ($\text{m}^3 \text{h}^{-1}$), T_i is time (h) and A_x is the field area (ha).

The TDN, $\text{NH}_4^+\text{-N}$, $\text{NO}_3\text{-N}$ and TDP exports (kg ha^{-1}) were calculated according to Equation 5 (Li *et al.*, 2020).

$$\text{Nutrient loss} = 10^4 * \sum R_o * C_i \quad 5$$

where C_i (mg L^{-1}) is the concentration of each nutrient.

2.4 Statistical Analysis

All statistical analyses were performed using MINITAB version 2021. The concentrations and loads of exported sediment and nutrients (particulate and dissolved) were subjected to descriptive statistics to determine the mean, standard deviation, coefficient of variation, minimum and maximum values. Analysis of variance (ANOVA) was carried out on the sediment and nutrient concentrations and exports for test of significance while means were separated using Fisher's least significant difference (LSD) test at $P \leq 0.05$ level of significance. Linear regression analyses were carried out to determine the relationships between the changes

in particulate N and P and dissolved nutrient (TDN, $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and TDP) exports and the influencing factors. The regression equation will take the form shown in Equation 6.

$$Y = \beta_0 + \beta_1 R + \beta_2 T + \beta_3 (R \times T) + \varepsilon \quad 6$$

Where: Y: Nutrient export, R: Rainfall amount (mm) during or shortly after fertilizer application, T: Fertilizer application timing, $R \times T$: Interaction term between rainfall and fertilizer timing to capture combined effects, β_0 : Intercept (baseline nutrient export when R and T are zero), β_1 , β_2 , β_3 : Regression coefficients indicating the magnitude and direction of each variable's influence, ε : negligible error due to human error.

3. Results and Discussion

3.1 Effect of Rainfall on Nutrient Export

The effect of rainfall on the export of dissolved nutrients from agricultural fields was assessed by examining the concentrations of nitrate-nitrogen ($\text{NO}_3\text{-N}$), ammonium-nitrogen ($\text{NH}_4\text{-N}$), total dissolved nitrogen (TDN), and total dissolved phosphorus (TDP) in runoff samples collected during various rainfall events throughout the maize cropping season. Over the course of the study, a total of 20 rainfall events were monitored, with rainfall amounts ranging from 29.72 mm to 393.77 mm (Table 1). $\text{NO}_3\text{-N}$ concentrations in the runoff samples averaged 35.30 ± 20.55 mg/L, with values ranging between 5.67 mg/L and 78.41 mg/L. A substantial variability in $\text{NO}_3\text{-N}$ was observed with rainfall events, as reflected by a high coefficient of variation (CV) of 58.21%. Nutrient loss from the maize field showed a strong association with rainfall events, particularly during periods of intense precipitation. Ammonium-nitrogen ($\text{NH}_4\text{-N}$) concentrations in runoff varied significantly, with a mean of 16.14 ± 11.66 mg/L (range: 1.23–43.27 mg/L) and a coefficient of variation (CV) of 72.22%, reflecting substantial fluctuation in response to rainfall intensity. Similarly, Total Dissolved Nitrogen (TDN) concentrations averaged 36.81 ± 20.79 mg/L, ranging from 6.01 to 79.57 mg/L, with a CV of 56.47%, suggesting that larger rainfall events mobilized higher nitrogen loads. Total Dissolved Phosphorus (TDP) displayed the greatest variability among the measured parameters, with a mean of 0.60 ± 0.67 mg/L (range: 0.02–2.74 mg/L) and a CV of 111.45%, indicating extreme sensitivity to runoff volume. These findings underscore a direct relationship between rainfall intensity and nutrient export, where higher rainfall events substantially increased nutrient concentrations in runoff. These findings reveal the significant impact of rainfall variability on the export of dissolved nutrients from maize fields, with implications for nutrient loss and potential water quality degradation.

Table 1: Effect of Rainfall on Nutrients Export from a maize Field at different growth stages

Growth stages	Rainfall (mm)	Nutrient Export (mg/L)			
		$\text{NO}_3\text{-N}$	$\text{NH}_4\text{-N}$	TDN	TDP
Seedling Stage	239.32	25.87	14.45	26.75	0.14
	56.11	3.91	0.88	4.52	0.03
Vegetative Stage (1 st fertilizer application – NPK 20:10:10)	159.73	57.25	22.85	63.78	0.97
	95.90	10.26	2.26	12.82	1.07
	292.60	36.81	13.89	38.31	2.39
	74.48	48.45	15.81	47.65	0.67
	146.61	52.65	31.33	55.23	1.14
Reproductive Stage (2 nd fertilizer application – Urea 46% nitrogen)	231.23	61.04	38.31	61.58	1.56
	119.23	31.28	17.16	34.11	0.54
	53.48	22.83	6.73	24.67	0.03
	317.56	46.62	10.16	47.01	1.28
	50.13	19.06	3.90	19.18	0.08
	149.42	68.58	30.56	70.28	0.11
	155.16	58.08	27.39	58.76	0.17
	393.77	30.95	18.25	32.05	1.12
	226.58	64.63	34.89	66.00	0.66
	34.06	11.31	4.52	13.86	0.00
Post-harvest	76.42	16.87	9.95	17.06	0.02
	29.72	8.95	0.78	10.11	0.00
	111.76	30.56	18.79	32.56	0.01
	Mean	35.30	16.14	36.81	0.60
	Std	20.55	11.66	20.79	0.67
	CV (%)	58.21	72.22	56.47	111.45
	Max	68.58	38.31	70.28	2.39
	Min	3.91	0.78	4.52	0.00

At the seedling stage, nutrient exports were relatively low despite a high total rainfall of 239.32 mm in one of the events. The average NO_3^- -N concentration was 25.87 mg/L, while NH_4^+ -N and TDN were 14.45 mg/L and 26.75 mg/L respectively, with very low TDP (0.14 mg/L). This suggests that early in the crop cycle—prior to major fertilization—nutrient loss is more dependent on residual soil nutrients and initial leaching from minor fertilizer residues or organic matter decomposition. A second, lower-rainfall event (56.11 mm) showed minimal nutrient export, reinforcing the link between rainfall intensity and nutrient mobilization.

The vegetative stage coincided with the first fertilizer application (NPK 20:10:10), and nutrient exports increased noticeably. With rainfall ranging from 74.48 mm to 292.60 mm, NO_3^- -N levels spiked (as high as 57.25 mg/L), while NH_4^+ -N ranged up to 31.33 mg/L, and TDN reached 63.78 mg/L. Notably, TDP concentrations increased sharply (up to 2.39 mg/L), indicating that phosphorus losses are highly responsive to both rainfall and nutrient input. The variability across events suggests that rainfall occurring soon after fertilizer application likely drove the increased nutrient export through surface runoff and leaching.

The productive stage followed the second fertilizer application (Urea 46% N). The data here reflect high variability in both rainfall (29.72 mm to 393.77 mm) and nutrient export. NO_3^- -N concentrations peaked at 68.58 mg/L, with consistent levels above 50 mg/L during moderate to heavy rainfall. Similarly, NH_4^+ -N and TDN values were elevated across most events, and although TDP remained lower overall, values up to 1.56 mg/L were recorded. The wide range of nutrient export values despite variable rainfall suggests that residual fertilizer, combined with rainfall intensity and soil saturation, plays a crucial role in determining nutrient losses during this stage.

The effect of rainfall amount on NO_3 -N export is shown in Figure 2. The positive relationship between rainfall amount and NO_3 -N loss can be attributed to the ability of higher rainfall volumes to transport greater amounts of soluble NO_3 -N from the soil surface. As rainfall intensity and runoff levels increase with larger events, more NO_3 -N is mobilized from the upper soil horizons where it is most concentrated. The kinetic energy of the raindrops may also promote the detachment and dissolution of NO_3 -N particles into runoff. Additionally, poor infiltration and increased overland flow associated with high rainfall rates reduce residence time for NO_3 -N interaction with soil particles, resulting in greater export.

A significant ($p < 0.05$) positive relationship with an R^2 value of 0.2134 (Figure 2), indicating that rainfall amount explained 21.3% of the variability in NO_3 -N concentrations. As rainfall amount increased, greater amounts (68.6 mg/L) of NO_3 -N were exported in the runoff. At low rainfall amounts below 100 mm, NO_3 -N concentrations were generally less than 40 mg/L, while at higher rainfalls above 200 mm, concentrations frequently exceeded 50 mg/L.

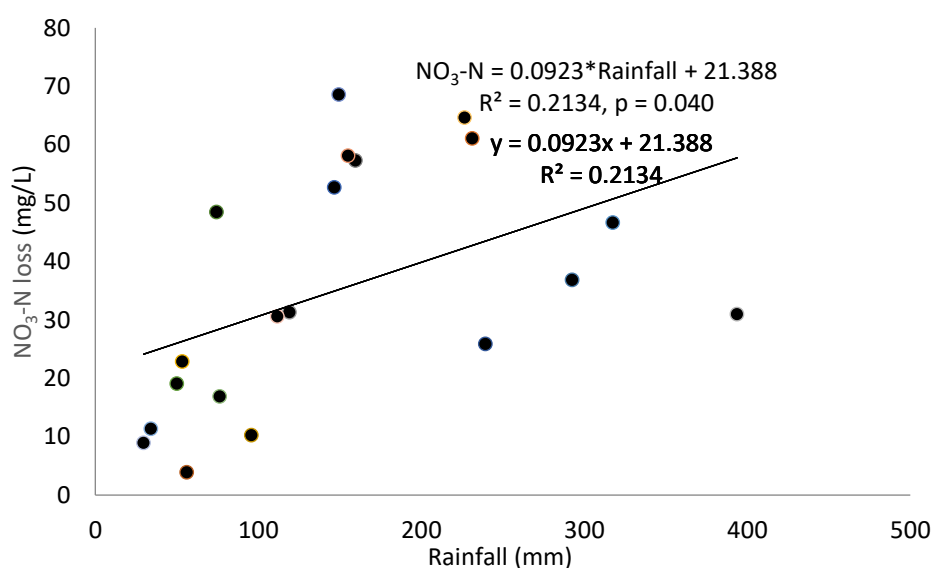


Figure 2: Relationships between rainfall events and NO_3 -N export

Despite the observed relationship between rainfall and nutrient transport, rainfall amount accounted for only 25.3% of the variability in NO_3^- -N concentrations. This suggests that while precipitation plays a role, other factors are significantly influential in governing NO_3^- -N losses. The availability of NO_3^- -N in the soil is influenced by multiple interrelated parameters, including the rate and timing of fertilizer application, the crop's nitrogen uptake pattern, antecedent soil moisture conditions, and inherent soil characteristics such as texture,

structure, and organic matter content (Das *et al.*, 2024). For example, excessive or poorly timed fertilizer application can result in nitrate accumulation in surface soils, increasing the potential for loss during subsequent rainfall events. These factors likely explain the wide variation in NO_3^- -N concentrations observed during rainfall events of similar magnitude. The positive correlation between rainfall amount and NO_3^- -N loss in this study aligns with findings by Wu *et al.* (2018), who reported increased concentrations and loads of NO_3^- -N in runoff following high-intensity rainfall events. They attributed this trend to enhanced runoff generation, detachment, and transport of nitrate from the upper soil layers. Conversely, Cheng *et al.* (2018) reported no significant relationship between rainfall amount and NO_3^- -N loss, which they attributed to variability in antecedent soil moisture, highlighting the importance of pre-event hydrological conditions in modulating nutrient export. This further underscores that rainfall amount alone is insufficient to predict nutrient loss without accounting for underlying soil and management factors.

3.1.2 Influence of rainfall amount on NH_4 -N export

Regression analysis also revealed a significant ($p < 0.05$) positive influence of rainfall amount on NH_4 -N export (Figure 2). Rainfall amount accounted for 20% of the variability in NH_4 -N concentrations based on the R^2 value. Higher rainfall totals led to increased NH_4 -N loss in the runoff (Figure 2). Most NH_4 -N concentrations were below 25 mg/L when rainfall amounts were less than 150 mm, but concentrations over 30 mg/L were measured at rainfalls above 250 mm. The correlation can be attributed to the high mobility of NH_4 -N in soils. NH_4 -N binds loosely to negatively charged soil particles through weak electrostatic bonds, keeping it easily detachable and soluble when dislodged into runoff. Greater runoff flows and velocities with larger rainfall events also facilitate NH_4 -N particle detachment and transport away from sorption sites. However, as with NO_3 -N, factors such as fertilizer inputs, mineralization rates, nitrification kinetics and moisture conditions which vary between events, likely contributing to NH_4 -N variability unrelated to rainfall. While a key determinant, rainfall alone does not fully control NH_4 -N loss.

3.1.3 Influence of rainfall amount on TDN export

A significant ($p < 0.05$) positive relationship was found between rainfall amount and TDN export (Figure 3). This R^2 of 0.2057 signifies that rainfall amount explained 20.6% of TDN concentration variability. TDN concentrations tended to be low (< 35 mg/L) at rain amounts under 150 mm and high (> 45 mg/L) when rainfall exceeded 250 mm. This suggests that greater rainfall quantities resulted in increasing losses of TDN, comprised of inorganic nitrate and ammonium ions as well as organic nitrogen species. Heavier rainfall likely mobilized more nitrogen from upper soil layers through particle detachment and dissolution (Zheng and Wang, 2021). Similarly to NO_3 -N and NH_4 -N, other factors like soil nitrogen content and crop uptake also impacted TDN concentrations between events.

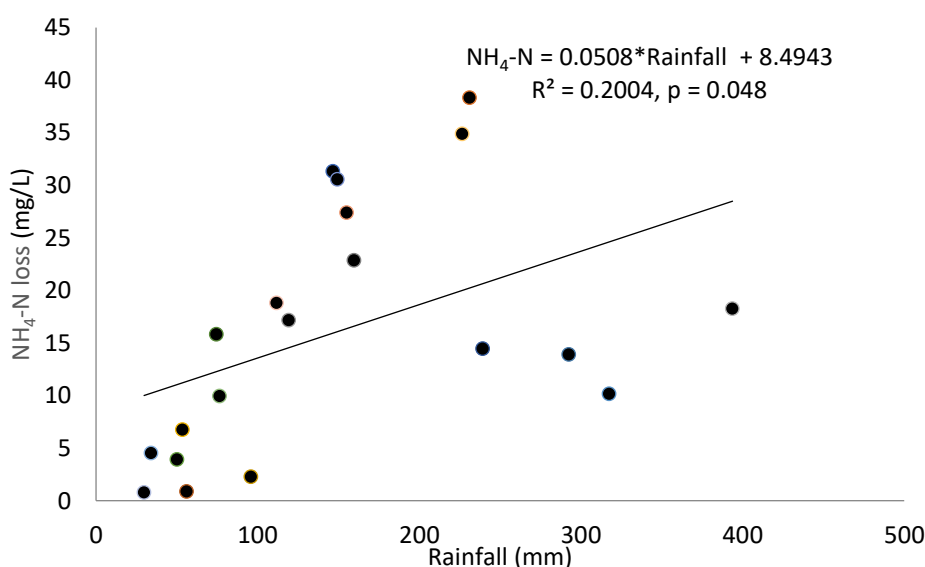


Figure 1: Relationships between rainfall events and NH_4 -N export

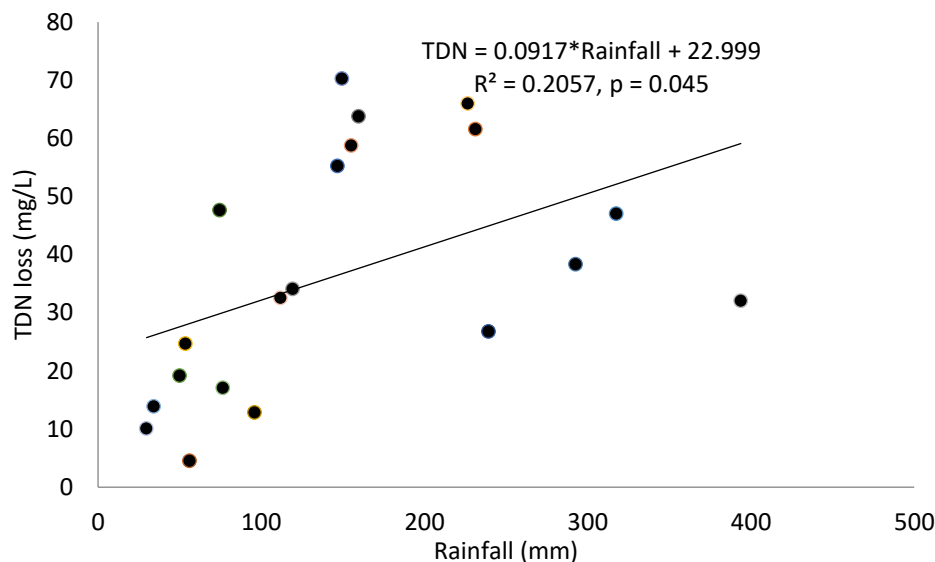


Figure 2: Relationships between rainfall events and TDN export

3.1.4 Influence of rainfall amount on TDP export

Rainfall amount showed a highly significant ($p = 0.001$) influence on total dissolved phosphorus (TDP) export (Figure 4). The R^2 value of 0.4503, indicate rainfall accounted for 45.03% of the variability in TDP concentrations. TDP levels clustered mostly under 0.5 mg/L at rainfall below 150 mm but commonly exceeded 1 mg/L when rainfall surpassed 250 mm. Unlike nitrogen, phosphorus exhibits low mobility in soils, as it tends to adsorb tightly to soil particles. However, high-energy rains appear particularly effective at dislodging and transporting dissolved phosphorus (Mackey *et al.*, 2019). With increasing runoff volumes and flow velocities at higher rainfalls, more phosphorus is shifted into soluble forms and carried away in solution (Zhang *et al.*, 2019). Soil phosphorus levels and management also likely influenced the degree of phosphorus loss between events. Generally, the significant relationships between rainfall and $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, TDN and TDP export signify that precipitation is a major controlling factor governing nitrate, ammonium and phosphorus loss from agricultural fields. Rainfall serves not only as a transport medium for nutrient movement but, when accompanied by high energy and intensity, also enhances the detachment of nutrients from soil particles (Chang *et al.*, 2020). However, the variability in nutrient concentrations between rainfall events highlights the additional roles of soil nutrient contents, crop conditions, fertilizer management, and event-specific meteorological factors in determining nutrient loss (Huo *et al.*, 2021; Yaşar Korkanç and Şahin, 2021). Management practices aimed at reducing nutrient loads in agricultural runoff should consider the link between nutrient loss and high rainfall events. Strategies such as cover cropping; conservation tillage and buffers may be particularly beneficial during months or seasons prone to high-intensity storms.

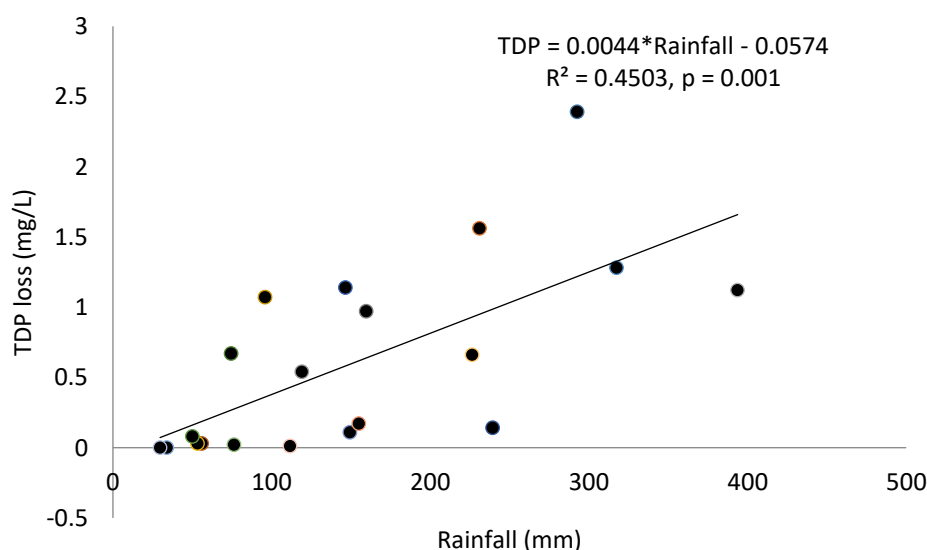


Figure 3: Relationships between rainfall events and TDP export

3.2 Influence of Fertilizer Application on Nutrient Export at different growth stage

The effect of fertilizer application on dissolved nutrient loss was analyzed by comparing the concentrations $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, TDN, and TDP in runoff between different cropping stages (Table 2).

In the initial seed germination stage prior to fertilization, nutrient concentrations were low, indicating minimal nutrient export. $\text{NO}_3\text{-N}$ averaged 14.57 ± 12.06 mg/L, $\text{NH}_4\text{-N}$ averaged 7.72 ± 7.49 mg/L, TDN averaged 15.60 ± 12.17 mg/L, and TDP averaged 0.17 ± 0.17 mg/L. Minimal nutrient mobilization is expected prior to fertilizer amendments, especially when residue cover from the preceding maize crop is still intact. Crop residues shield the soil surface from raindrop detachment and maintain favourable conditions for water infiltration, reducing runoff volumes that can transport dissolved nutrients (Blanco-Canqui *et al.*, 2017). Surface crop residue cover generally exceeded 50% during this initial period based on visual field estimates. The residues likely promoted infiltration over runoff and impeded contact between rainfall and bare soil patches, minimizing detached nutrient loads. Furthermore, soil nutrient levels are typically depleted after crop harvest and over the non-growing season without fresh fertilizer inputs, reducing source availability. The low nutrient concentrations found in runoff during seed germination align with previous studies demonstrating the protective effects of crop residue cover retention on dissolved nutrient loss (Gilley *et al.*, 2014).

Table 2: Influence of Fertilizer Application on Nutrient Export at different cropping stage

Cropping stage	Fertilizer dose	Nutrient Loss (mg/L)			
		$\text{NO}_3\text{-N}$	$\text{NH}_4\text{-N}$	TDN	TDP
Seedling Stage	2	14.57 ± 12.06^b	7.72 ± 7.49^a	15.60 ± 12.17^b	0.17 ± 0.17^b
Vegetative Stage (1st fertilizer application – NPK 20:10:10)	5	41.44 ± 17.58^a	17.06 ± 9.55^a	43.56 ± 18.12^{ab}	1.26 ± 0.64^a
Reproductive Stage (2nd fertilizer application – urea 46% nitrogen)	12	37.42 ± 21.43^a	16.98 ± 12.83^a	37.93 ± 21.28^{ab}	0.48 ± 0.56^b
2nd fertilizer application (urea 46% Nitrogen)					
Post-harvest	1	30.29 ± 11.10^{ab}	18.63 ± 0.17^a	32.63 ± 0.06^{ab}	0.02 ± 0.01^b
		P=0.039	P=0.30	P=0.03	P=0.000

Means that do not share a letter are significantly different

After the first application of NPK compound fertilizer during the vegetative stage of maize development, a substantial rise in dissolved nutrient concentrations in runoff was observed compared to levels recorded during the seedling stage. Specifically, $\text{NO}_3\text{-N}$ concentrations increased significantly to an average of 41.44 ± 17.58 mg/L, while total dissolved nitrogen (TDN) rose to 43.56 ± 18.12 mg/L. Total dissolved phosphorus (TDP) experienced a sharp increase, reaching 1.26 ± 0.64 mg/L from the 0.17 ± 0.17 mg/L obtained from the seedling stage. The 285% rise in $\text{NO}_3\text{-N}$ concentration underscores extensive nitrification of the ammonium component of the applied NPK fertilizer. This transformation was likely accelerated by warm and moist soil conditions, which are conducive to microbial activity responsible for nitrification.

At this early vegetative stage, the maize plants had not yet developed sufficient root mass or canopy coverage to take up the available nutrients effectively. As a result, the highly mobile nitrate ions remained in the soil solution and were easily transported via surface runoff rather than absorbed by the crop. This observation is consistent with findings by Sebilo *et al.* (2013), who reported that as much as 60% of applied nitrogen fertilizer can be lost through leaching and runoff instead of contributing to crop uptake. The 216% increase in TDP concentration similarly indicates that a significant portion of the applied phosphorus was lost in runoff shortly after fertilization. The limited vegetative cover and low phosphorus uptake capacity of the young maize plants, combined with insufficient incorporation of fertilizer into the soil, facilitated this export. These results are in agreement with Smith *et al.* (2016), who found that soils with sparse vegetation or exposed surfaces experience higher fluxes of dissolved nutrients following fertilizer application. Collectively, the findings emphasize the importance of synchronizing fertilizer application with crop nutrient demand and growth stage to minimize nutrient loss and maximize efficiency.

The second application of urea fertilizer, applied as a split dose during the maize stem elongation phase, did not result in a further significant increase in nutrient concentrations beyond those observed following the initial NPK application. Measured values for $\text{NO}_3\text{-N}$ averaged 37.42 ± 21.43 mg/L, $\text{NH}_4\text{-N}$ averaged 16.98 ± 12.83 mg/L, while TDN and TDP averaged 37.93 ± 21.28 mg/L and 0.48 ± 0.56 mg/L, respectively. The

relatively stable nutrient levels at this stage are attributable to the improved physiological and morphological conditions of the maize plants, particularly the onset of rapid biomass accumulation and canopy expansion. These conditions promote higher nutrient uptake efficiency, thereby reducing the availability of soluble nutrients for loss via runoff.

Moreover, the increased vegetative cover likely enhanced surface protection by reducing raindrop impact and overland flow energy, thus contributing to the mitigation of nutrient detachment and transport. This observation corroborates the findings of Liang *et al.* (2017), who demonstrated that delaying fertilizer applications until after crop establishment significantly decreased dissolved nutrient losses in runoff compared to early-season applications. Similarly, Noulas *et al.* (2023) highlighted that split fertilizer application strategies, which align nutrient input with crop developmental stages and physiological needs, reduce nitrogen and phosphorus losses. These results reinforce the principle that synchronizing fertilizer application with crop nutrient demand and growth dynamics can significantly lower the risk of nutrient runoff. In particular, avoiding fertilization during the early stages of crop growth before the full development of canopy and root systems can minimize nutrient leaching and improve overall fertilizer use efficiency.

During the final post-harvest sampling, conducted approximately one month after maize reached physiological maturity, nutrient concentrations in runoff exhibited a general decline compared to in-season levels, though they remained elevated relative to pre-fertilization baselines. Specifically, the mean concentrations were 30.29 ± 1.10 mg/L for NO_3^- -N, 18.63 ± 0.17 mg/L for NH_4^+ -N, 32.63 ± 0.06 mg/L for total dissolved nitrogen (TDN), and 0.02 ± 0.01 mg/L for total dissolved phosphorus (TDP). The cessation of crop nutrient uptake following senescence coincided with the ongoing decomposition of residual maize biomass, a process likely responsible for the continued, albeit diminished, mobilization of nutrients into surface runoff.

Despite the completion of harvest, residual plant matter provided limited but notable surface cover, contributing to the mitigation of erosion and nutrient detachment. The lower post-harvest concentrations compared to those recorded during the active growing season suggest partial nutrient assimilation by the crop during its life cycle. However, the persistence of residual nitrogen and phosphorus in the soil, coupled with ongoing mineralization, left a portion of the applied nutrients susceptible to leaching and runoff. These findings align with earlier research by Hanrahan *et al.* (2018) and Wang *et al.* (2020), which reported gradual losses of residual nutrients during the inter-cropping period due to leaching. The observed post-harvest nutrient dynamics underscore the importance of incorporating nutrient-capturing strategies, such as cover cropping or the inclusion of deep-rooted perennials in rotational systems. These approaches can enhance nutrient retention during fallow periods, reducing off-season losses and promoting long-term soil fertility and water quality conservation.

4. Conclusion

The study assessed the effects of rainfall and fertilizer application on nutrient loss from maize field. It was concluded that the amount of rainfall significantly and positively influenced the export of dissolved nutrients (NO_3^- -N, NH_4^+ -N, TDN, TDP) in surface runoff from the maize field. This underscores that rainfall-driven erosion processes play a critical role in the mobilization of particulate nutrients. Early-season fertilization, when crops were not yet established, led to sharp increases in nutrient concentrations compared to pre-fertilization levels. In contrast, subsequent split applications of fertilizer, applied in alignment with crop growth, did not result in further increases in nutrient concentrations. These findings highlight the importance of synchronizing nutrient inputs with plant demand to minimize the mobilization of dissolved nutrients into runoff.

References

- Abdulraheem, M.I., Syed, MZAN., Li L., Ahmed, S., Wei, W., Su R., Li B., Li, C., Zhang, Y., Feng, Y., and Hu, J. 2022. Soil Fertility Management: Issues and Challenges in Tropical Areas of Nigeria. In *Ecosystem Services: Types, Management and Benefits*. Nova Publisher Inc. 313 - 326
- Abebe, Z. and Feyisa, H. 2017. Effects of nitrogen rates and time of application on yield of maize: Rainfall variability influenced time of N application. *International Journal of Agronomy*, 2017(1):1-10. <https://doi.org/10.1155/2017/1545280>.
- Are, K.S., Guo, H. and Li, Y. 2022. Land Use Types Influence Diffuse N and P Entering a River in an Agricultural Watershed: Evidence from Compound-Specific Stable Isotope. *Moor Journal of Agricultural Research*, 23(1): 23-36.

- Chang, CT., Shih, YT., Lee, C., Lee, JY., Lee, TY., Lin, TC., and Huang, J. C. 2020. Effects of land cover and atmospheric input on nutrient budget in subtropical mountainous rivers, northeastern Taiwan. *Water*, 12(10): 1-18. <https://doi.org/10.3390/w12102800>.
- Davies, B., Coulter, JA. and Pagliari, PH., 2020. Timing and rate of nitrogen fertilization influence maize yield and nitrogen use efficiency. *Plos One*, 15(5): 1-19. <https://doi.org/10.1371/journal.pone.0233674>.
- Das, S., Mohapatra, A., Sahu, K., Panday, D., Ghimire, D. and Maharjan, B., 2024. Nitrogen dynamics as a function of soil types, compaction, and moisture. *PLos one*, 19(4): 1-19. <https://doi.org/10.1371/journal.pone.0233674>.
- Gilley, JE., Risse, LM. and Eghball, B. 2014. Managing Runoff Following Manure Application. *Journal of Soil and Water Conservation*, 57(6): 530-533.
- Hanrahan, BR., Tank, JL., Christopher, SF., Mahl, UH., Trentman, MT. and Royer, TV. 2018. Winter cover crops reduce nitrate loss in an agricultural watershed in the central US. *Agriculture, Ecosystems and Environment*, 265: 513-523.
- Harindintwali, JD., Zhou, J., Muhoza, B., Wang, F., Herzberger, A. and Yu, X. 2021. Integrated eco-strategies towards sustainable carbon and nitrogen cycling in agriculture. *Journal of Environmental Management*, 293: 1-12. <https://doi.org/10.1016/j.jenvman.2021.112856>
- Huo, J., Liu, C., Yu, X., Chen, L., Zheng, W., Yang, Y., and Yin, C. 2021. Direct and Indirect Effects of Rainfall and Vegetation Coverage on Runoff, Soil Loss, and Nutrient Loss in a Semi-humid Climate. *Hydrological Processes*, 35(1): 1-12.
- Khan, MN., Mobin, M., Abbas, Z.K. and Alamri, SA., 2018. Fertilizers and their contaminants in soils, surface and groundwater. In *Encyclopaedia of the Anthropocene*, 5: 225-240.
- Li, Y., Wang, C. and Tang, H. 2020. Research Advances in Nutrient Runoff on Sloping Land in Watersheds. *Aquatic Ecosystem Health and Management*, 9(1): 27-32.
- Liang, K., Zhong, X., Huang, N., Lampayan, R.M., Liu, Y., Pan, J., Peng, B., Hu, X. and Fu, Y. 2017. Nitrogen losses and greenhouse gas emissions under different N and water management in a subtropical double-season rice cropping system. *Science of the Total Environment*, 609: 46-57.
- Noulas, C., Torabian, S. and Qin, R. 2023. Crop nutrient requirements and advanced fertilizer management strategies. *Agronomy*, 13(8): 1-10. <https://doi.org/10.3390/agronomy13082017>.
- Ogundele, AT. and Owoade, OA. (2016). Implications of Biomass Energy Production and Utilization on Sustainable Forest Management in Ibarapa Region of Oyo State, Nigeria. *International Journal of Geography and Environmental Management*, 2(1): 61-75.
- Omokaro, G., Idama, V., Aireughian, E. and Michael, I., 2024. Water Resources, Pollution, Integrated Management and Practices in Nigeria-An Overview. *American Journal of Environmental Economics*, 3(1): 5-18.
- Orimoloye, JR., Akinbola, GE., and Achi, CA. 2018. Variability Evaluation of Selected Soil Properties in Three Locations in Oyo State, South West Nigeria. *Ibadan Journal of Agricultural Research*, 14(1): 1 - 13
- Rahutomo, S., Kovar, JL. and Thompson, ML. 2018. Inorganic and organic phosphorus in sediments in the Walnut Creek Watershed of central Iowa, USA. *Water, Air, & Soil Pollution*, 229: 1-12.
- Rashmi, I., Karthika, KS., Roy, T., Shinoji, KC., Kumawat, A., Kala, S. and Pal, R. 2022. Soil Erosion and sediments: a source of contamination and impact on agriculture productivity. In *Agrochemicals in Soil and Environment: Impacts and Remediation*. Springer Nature Singapore. 313-345.
- Sebilo, M., Mayer, B., Nicolardot, B., Pinay, G. and Mariotti, A. 2013. Long-term Fate of Nitrate Fertilizer in Agricultural Soils. *Proceedings of the National Academy of Sciences*, 110(45): 18185-18189.
- Smith, DR., King, KW., Johnson, L., Francesconi, W., Richards, P., Baker, D. and Sharpley, AN. 2015. Surface Runoff and Tile Drainage Transport of Phosphorus in the Midwestern United States. *Journal of Environmental Quality*, 44(2): 495-502.

Wang, J., Guo, J., Li, G., Lu, W., and Lu, D. 2025. Effects of different fertilizer combinations on the yield and nitrogen use efficiency of summer maize in Jiangsu Province, China. *Scientific Reports*, 15(1): 124-158.

Wang, S., Fu, B., Piao, S., Lü, Y., Ciais, P., Feng, X. and Wang, Y. 2020. Reducing Future Nutrient Losses to Control Eutrophication in the Chinese Inland Waters. *Nature Communications*, 11(1): 1-10.

Waring, ER., Sawyer, J., Pederson, C. and Helmers, M., 2022. Impact of nitrogen fertilizer timing on nitrate loss and crop production in northwest Iowa. *Journal of Environmental Quality*, 51(4): 696-707.

Wu, L., Peng, M., Qiao, S. and Ma, X. 2018. Assessing Impacts of Rainfall Intensity and Slope on Dissolved and Adsorbed Nitrogen Loss under Bare Loessial Soil by Simulated Rainfalls. *Catena*, 170: 51–63.

Yaşar Korkanç, S. and Şahin, H. 2021. The Effects of Mulching with Organic Materials on the Soil Nutrient and Carbon Transport by Runoff under Simulated Rainfall Conditions. *Journal of African Earth Sciences*, 176: 104-152.

Zhang, R., Li, M., Yuan, X. and Pan, Z. 2019. Influence of Rainfall Intensity and Slope on Suspended Solids and Phosphorus Losses in Runoff. *Environmental Science and Pollution Research*, 26(33): 33963–33975.

Zheng, W., and Wang, S. 2021. Extreme Precipitation Accelerates the Contribution of Nitrate Sources from Anthropogenic Activities to Groundwater in a Typical Headwater Area of the North China Plain. *Journal of Hydrology*, 603(C): 1-12.