The dynamic relation between fertilization, precipitation and the diffusion of agricultural non-point pollution in Hainan Island

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With the increasing demand for crops, the excessive application of fertilizers has gradually become a significant factor affecting water quality. Therefore, studying the relationship between agricultural fertilizer runoff and water quality is crucial for the sustainable development of agricultural production. The present study sets up a new dynamic model of nitrogen fertilizer loss, introducing variables such as precipitation, fertilization application during dry and rainy seasons, and their lagged and interaction terms. The paper analyzed the issue of fertilizer runoff under the complex interactions of various factors, including spatial and temporal scales and climatic conditions, and explored the relationship between agricultural activities and water quality changes in the context of sustainable development. Due to Hainan Island's independent river system, which is free from transboundary pollution, and its low level of industrial pollution, it provides an excellent sample for assessing the impact of agricultural non-point source pollution on water quality. Based on watershed monitoring data from Hainan Island, this study draws the following conclusions: 1. Precipitation exhibits a pronounced seasonal influence on total nitrogen concentration. 2. Nitrogen fertilizer enters into water bodies through precipitation, resulting in a lag effect on total nitrogen concentration. 3. The influence of grain and tropical crops on nitrogen loss is less significant, while cash crops will trigger the nitrogen overloading of rivers in scenarios where they account for a high proportion of the planting structure of the sown area.

KEYWORDS

agricultural non-point source pollution, fertilizer, precipitation, LSDVC, planting structure

1 Introduction

With the continuous growth of the global population, the demand for food is rising. Fertilizers are widely used as an important tool for improving crop yields. However, the utilization rate of fertilizers is relatively low in many countries due to outdated technologies and inappropriate usage strategies. China, for example, is a major consumer of fertilizers, accounting for 32% of the world's fertilizer usage (Zhang et al., 2010). However, the utilization rates of nitrogen and phosphorus fertilizers for rice production in China are only between 40% and 65% and 15% and 25%, respectively (Wang et al., 2018). The inefficient long-term utilization of fertilizer leads to the discharge of a large number of nutrients, such as nitrogen and phosphorus, into water bodies through pathways of runoff and leaching. According to data from "The Bulletin of the Second National Pollution Source Census" (Ministry of Ecology and Environment of the People's Republic of China, 2020), the amount

of nitrogen emission by water pollutants in the whole country totaled 3,041,400 tons in 2017, of which emissions from the planting industry accounted for about 23.66%, or 719,500 tons. Over-fertilization has already caused significant harm to the ecological environment and requires more attention.

Water pollution caused by fertilizer application in farmland falls under the category of agricultural non-point source pollution, by which discharged solid or dissolved pollutants, such as nitrogen, phosphorus, pesticides, and organic or inorganic substances from rural areas, enter into water bodies through surface runoff, agricultural drainage and groundwater seepage, resulting in significant pollution. Agricultural non-point source pollution is difficult to predict due to its characteristics of a wide pollution range, highly dispersed sources, lag effects, and randomness of occurrence in both time and space. There is evidence that cultivated land systems has significant influence on surface water quality, and the fertilizer application has become the major source of agricultural non-point source pollution (Zou et al., 2020; Tim and Jolly, 1994).

To analyze the impact of non-point source pollution of agricultural fertilizer on surface water quality, this study selects Hainan Island as the research object. It offers the following unique advantages:

(1) A high proportion of agriculture. Given the relatively slow pace of industrial development in Hainan Province, agriculture plays a significant role. Therefore, it is easier to focus on the influence of agricultural pollution on water pollutants here;

(2) No transit water pollution. Hainan Island, as a closed island, does not encounter transit water pollution, and thus is not subjected to the influence of upstream and downstream transit water pollution, ensuring accuracy when studying the factors influencing agricultural fertilizer loss in this location;

(3) Significant spatiotemporal characteristics. Hainan Island experiences distinct dry and rainy seasons, with overall abundant precipitation. These climatic features result in a relatively lighter carrying effect and obvious spatiotemporal changes in agricultural non-point source pollutants, which is conducive to comparative studies on the effects of precipitation on fertilizer discharge.

There are many methods for studying the agricultural non-point source pollution, which are generally divided into empirical models, such as ECM (Han et al., 2011), IECM (Cheng et al., 2018) and HSM (Zhang et al., 2019), and mechanistic models, such as SWAT (Chen et al., 2019) and AGNPS (Haregeweyn and Yohannes, 2003). Most models perform well in the perspective of simulation results; however, their disadvantages regarding data sensitivity and regional applicability are quite pronounced. On one hand, the estimation accuracy of these models depends on numerous parameters, requiring large amount of input data and extensive available information, making their calibration and validation highly challenging (Xin et al., 2017). On the other hand, although most methods demonstrate good performance in developed countries, they may not be applicable for developing countries due to disparities between actual environmental conditions and

experimental settings (de Oliveira et al., 2017). To estimate pollution load from agricultural non-point source, some scholars have adopted inventory analysis methods, utilizing readily accessible input production factors derived from statistical data to estimate pollution loads (Chen et al., 2006; Zou et al., 2020).

Due to the characteristics of agricultural non-point source pollution, it is not appropriate to simply describe the emission quantities of pollutants or their corresponding proportions as contributors to water pollution. Therefore, when conducting a macro-level analysis of the levels and trends of non-point source pollution of agricultural fertilizer, especially in a vast country like China, it is essential to employ a reliable estimation algorithm (model) and a supporting indicator system. Without such a framework, integrating diverse data and materials becomes challenging, making it even more difficult to draw scientific conclusions.

Based on existing research, two key issues related to the effects of pathways of agricultural non-point source pollution on water quality should be considered (Jin and Wu, 2008): 1. The proportions of pollutants emitted from agricultural productive activities that ultimately enter water bodies. 2. The hydrological conditions of water bodies as they determine increases and reductions in pollutant concentrations.

The amount of fertilizer applied provides the material basis of the discharge of pollutants from agricultural non-point sources (Bulut and Aksoy, 2008; Liu and Liang, 2019; Greenwood et al., 1989; Zhang et al., 2004), and the main factor driving fertilizer discharge is precipitation. Unabsorbed and unvolatile fertilizers continuously accumulate before precipitation, and can act as pollutants when they enter water bodies through runoff after precipitation. However, the processes by which pollutants enter water bodies are influenced by various factors, such as land use conditions, topography, hydrological characteristics, climate and weather, all of which leads to great spatiotemporal heterogeneity (Huang et al., 2015; Zhou et al., 2021; Wang et al., 2022; Mihiranga et al., 2021). Moreover, precipitation plays a dual role in the quality of water bodies: it has a carrying effect by bringing fertilizers into water bodies, increasing the total amounts and concentrations of pollutants in the water, as well as a dilution effect by enhancing the flow and velocity of water bodies, increasing the dilution and diffusion capacity of pollutants, facilitating water self-purification, and reducing pollutant concentration (De Girolamo et al., 2020).

To analyze the impact of agricultural fertilizer runoff on surface water quality, this study establishes a dynamic model that incorporates lag terms and interaction terms based on the mediating effect of precipitation (including carrying and dilution effects). The model is designed to explore the relationship between agricultural fertilization practices and surface water quality while identifying the impact of agricultural non-point source pollutants on water quality. The paper provides a reliable analytical method to promote sustainable agricultural development.

2 Study area

2.1 Regional profile

The present study focuses on the major rivers on Hainan Island, which is located in the northwest area of the South China Sea. Hainan Island is separated from Guangdong Province by the Qiongzhou Strait

FIGURE 1
Locations of water quality monitoring stations in Hainan Island.
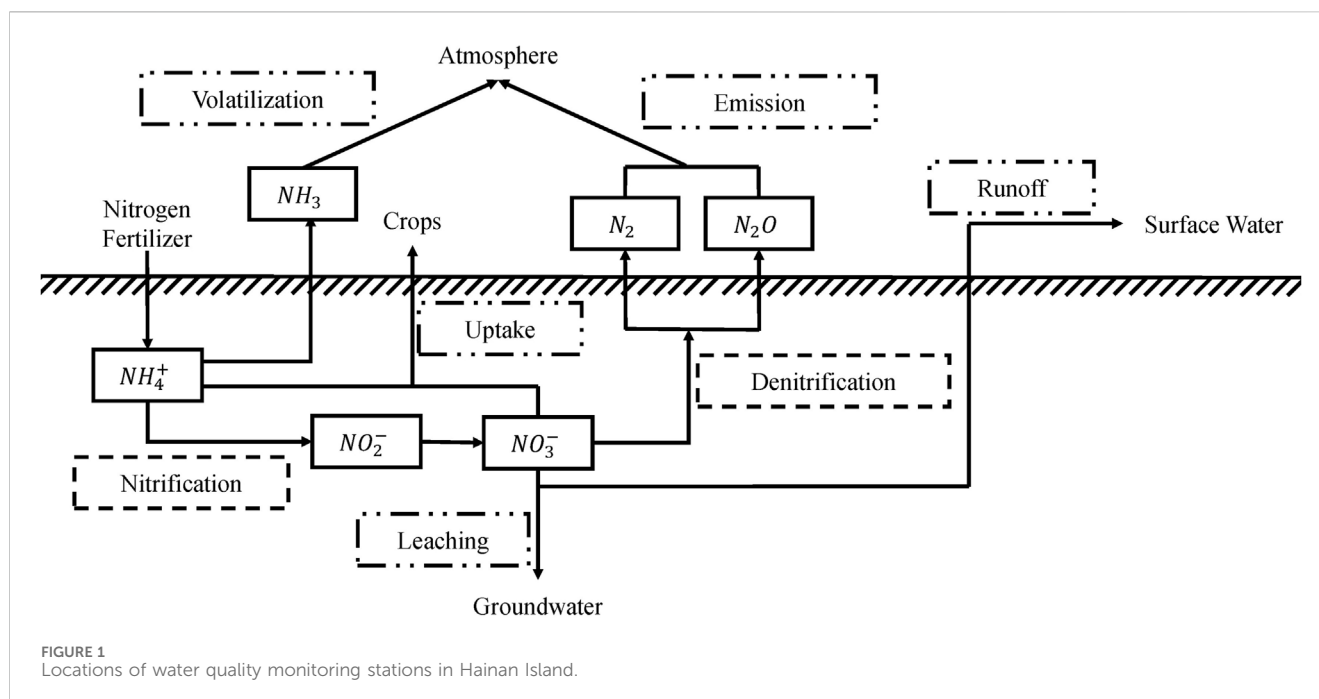
to the north and from Guangxi Province and Vietnam by the Beibu Gulf to the west ($18°10'$N~$20°10'$N, $108°37'$E~$111°03'$E).

Hainan Island is located at the northern edge of the tropics and experiences a warm and hot climate throughout the year. The rainfall on Hainan Island is abundant, with distinct rainy and dry seasons. The dry season spans from November to April, while the rainy season extends from May to October, with frequent typhoons. The rainy season contributes 80%–90% of the annual rainfall, and rainfall during the typhoon season in August, September and October accounts for about 70% of the annual rainfall. Hainan Island presents a terrain of a central highland surrounded by lower areas. With Wuzhi Mountain as its highest point, located at its center, the elevation gradually decreases outward, forming an annular and multi-level layered structure. Due to the geomorphological characteristics of Hainan Island, rivers flow radially from the central mountainous or hilly areas towards the periphery, forming a radially patterned water system. The rivers are numerous, with steep gradients, short lengths and relatively low flow.

In terms of pollutant emissions, according to the "Second National Pollution Source Census Bulletin of Hainan Province" released in 2021 (Department of Ecology and Environment of Hainan Province, 2021). Hainan Province discharged a total of 41,789 tons of nitrogen in 2017, of which the agricultural sector accounted for 39.17%, or 16,369.16 tons. The total nitrogen discharge of the whole country in the corresponding period was 304.14 million tons, of which the agricultural contribution was only 23.66%, or 719,500 tons.

2.2 Water quality measurement

The water quality data was collected by National Surface Water Quality Stations which were established by Chinese government for the real-time, continuous and remote monitoring of water quality conditions in key sections of major rivers. The water quality data primarily includes parameters such as pH, dissolved oxygen, permanganate index, ammonia nitrogen, total nitrogen, total phosphorus and chlorophyll-α. A total of 27 Water Quality Monitoring Stations have been established at points along 20 rivers on Hainan Island; they are distributed throughout 11 cities and counties, including Haikou, Sanya, Danzhou, Wenchang, Qionghai, Wanning, Chengmai, Lingao, Ledong, Changjiang and Lingshui. Figure 1 illustrates the rivers within Hainan Island and the locations of the Water Quality Monitoring Stations. By virtue of these stations, we have a comprehensive understanding of water quality conditions in the rivers in Hainan Province, providing crucial data for water quality management and environmental protection.

Since agricultural fertilizer pollutants primarily consist of nitrogen and phosphorus, and considering the main pollution characteristics of Hainan Island, this study identifies total nitrogen as the primary focus of the pollution research.

2.3 Characteristics of changes in water quality, fertilizer application and precipitation

Table 1 summarizes the annual average total nitrogen concentration, total nitrogen loss and total fertilizer application in the watersheds of monitoring stations, as well as the proportions of sown areas occupied by cash crops at the 27 water quality monitoring stations in 2021. It can be observed from the table that total nitrogen pollution was relatively severe in the rivers of Hainan Island during this time. The total nitrogen loss at various water quality monitoring stations in 2021 was approximately 371,111 tons. According to the requirements for

TABLE 1 Annual average concentrations of total nitrogen, total nitrogen loss and nitrogen fertilizer application, and proportion of sown area allocated for cash crops at the water quality monitoring stations in 2021.

Quality monitoring stations	Annual average total nitrogen concentrations (mg•L⁻¹)	Total nitrogen loss (tonnes)	Nitrogen fertilizer application (tonnes)	Total sown area (hectares)	Proportion of sown area allocated for cash crops (%)
Bairentan Power Station	1.83	717.25	4,719.13	20,830.77	38.36
Chahekou	1.74	1,062.69	1703.67	6,601.20	37.96
Daxi Village	1.44	622.72	4,674.89	87,140.34	28.18
Fenhong Bridge	1.00	314.12	4,095.37	22,991.67	26.88
Hele Bridge	2.03	1,035.82	833.45	4,843.73	30.29
Houan Bridge	0.99	349.88	1,375.38	6,545.75	26.00
Houli Village	1.45	4,327.64	11,218.12	39,738.36	45.21
Housha Village	2.10	396.50	622.84	5,555.68	25.51
Kuajie Bridge	0.72	1,177.07	2,917.50	17,559.07	29.21
Luole	2.14	879.53	3,618.74	24,481.90	49.22
Lezhong	0.64	482.75	2,988.19	19,475.25	20.92
Longjiang	0.92	1,806.24	10,389.75	20,262.92	42.00
Longtang	1.23	4,979.14	10,997.32	21,201.38	50.71
Nongken Rubber Institute First Squad	1.10	79.41	1,230.90	2,891.23	27.84
Liupo Water Gate	1.83	463.66	3,435.63	42,328.88	33.52
Qunyin Dam	1.15	249.18	4,212.87	50,393.00	22.56
Fangru	1.36	4,992.62	302.52	1,422.16	23.63
Shankou	0.90	2,140.61	24,514.37	34,059.24	31.53
Shangqiao Village	1.30	708.63	4,160.80	6,647.17	52.12
Shuiyaxinqu	1.67	683.24	1,506.18	7,611.56	30.57
Tenghe River Bridge	1.49	203.12	3,366.66	43,516.80	41.80
Tingzhou	0.97	2,439.04	11,079.72	23,159.41	30.71
Xizai Village	0.95	701.30	4,046.14	8,899.81	37.56
Yacheng Bridge	1.45	1,046.09	3,488.97	11,930.19	28.53
Yanzhou River Mouth	1.69	461.71	1,595.93	10,911.05	27.31
Yangtouwaicun Bridge	1.61	4,307.20	3,059.78	3,360.82	54.78
Zhonghe Bridge	2.01	484.43	3,521.76	26,424.48	21.36

Class III water quality in the Chinese standard "GB 3838–2002 Environmental Quality Standards for Surface Water," the total nitrogen concentration in the water should be less than 1.0 mg/L. However, among the 27 monitoring stations, 19 presented an annual average total nitrogen concentration exceeding 1.0 mg/L, while only 8 stations showed below 1.0 mg/L. This indicates that the total nitrogen concentrations at the majority of these stations exceeded the relevant standards.

For the fertilizer application, at these stations, the total levels of fertilizer application for agricultural production reached approximately 129,677 tons in 2021, with the proportion of sown area allocated for cash crops ranging from 20.92% to 54.78%.

2.4 Data sources

The present study primarily utilizes weekly measured data of total nitrogen concentration and nitrogen loss at water quality monitoring stations across Hainan Island, as well as data on crop planting area, fertilizer application and precipitation in 2021. The data were obtained through the following sources.

2.4.1 Nitrogen loss and total nitrogen concentration

The water quality data were derived from 27 national surface water monitoring stations on Hainan Island. The data are collected every 4 h automatically. For this study, total nitrogen data from

FIGURE 2
Mechanisms and main processes of nitrogen fertilizer loss from agricultural land.
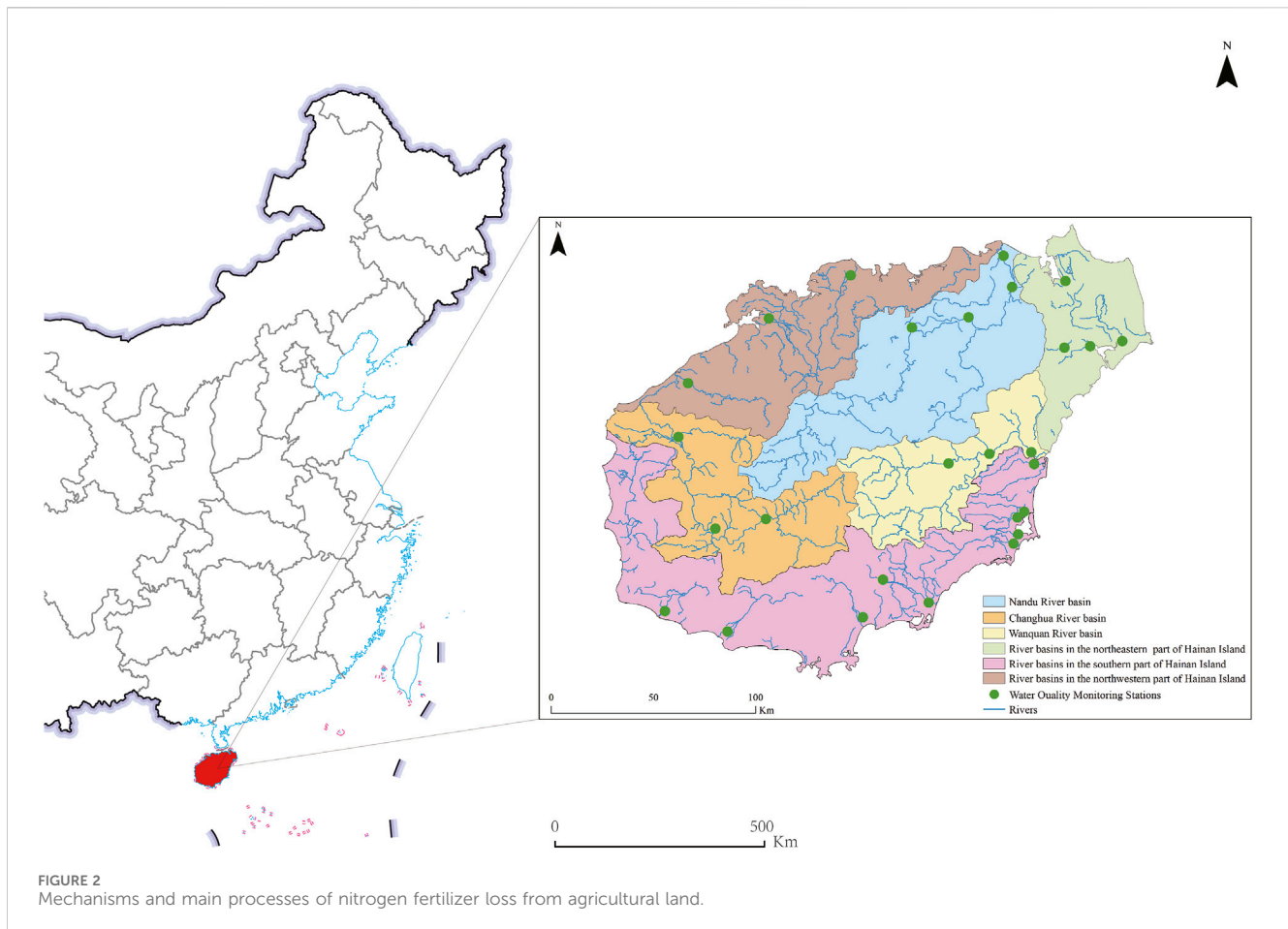
January 1st to December 30th were obtained from 27 monitoring sections for analysis. Weekly average total nitrogen concentration is here calculated based on the measured concentrations, and the total nitrogen loss is calculated using the total nitrogen concentration and flow rate at the monitoring stations.

2.4.2 Sown area, fertilizer applications and fertilization intensities

The data on planting area, total quantity of nitrogen fertilizer applied and nitrogen fertilization intensities were obtained from watersheds whereat the water quality monitoring stations are located. The relevant information has been estimated based on data from the "Hainan Statistical Yearbook" regarding crop sown area and fertilizer application, cultivated land area within the watersheds of the water quality monitoring stations, as well as cultivation technical standards for crops and other relevant information for China and Hainan province.

2.4.3 Precipitation

Precipitation data for watersheds whereat the monitoring stations are located have been derived from the ERA5-Land hourly dataset from 1950 to the present, provided by the European Centre for Medium-Range Weather Forecasts (ECMWF). The weekly precipitation for each city and county has been calculated from the dataset.

3 Theoretical analysis and methods

3.1 Theoretical analysis

3.1.1 Mechanism of nitrogen fertilizer loss in farmland

The mechanism of nitrogen fertilizer loss in farmland is illustrated in Figure 2. According to studies by He et al. (2001) and Huang et al. (2021), the schedules and amounts of fertilizer application in agricultural production are determined by the local cropping system. Following the application of nitrogen fertilizers, nitrogen undergoes several transformations across different phases. Initially, a portion of ammonium (NH_4^+) may be converted in to nitrite (NO_2^-) and nitrate (NO_3^-) through nitrification. Nitrate is one of the primary forms of nitrogen taken up by crops. In addition, a part of ammonium is also taken up by corps for growth. Nitrate and nitrite may be subsequent converted back to nitrogen gas (N_2) and nitrous oxide (N_2O) through denitrification and volatilize into atmosphere. Meanwhile, Nitrite, being water-soluble, may be lost through precipitation by leaching into groundwater or runoff into surface water. This study primarily focuses on the issue of nitrogen loss through surface runoff. For this pathway, the main factors influencing the pollution load of the runoff include the characteristics of the farmland and crops, precipitation features, and the environmental characteristics of the runoff, which together

determine the solute output that affects nitrogen loss through surface runoff.

3.1.2 The "substance-dynamic-factor" conceptual model of nitrogen loss in farmland

Based on the mechanisms of nitrogen fertilizer loss, Hou et al. (2008) proposed the conceptual model of "Substance Dynamic Factor" for nitrogen loss on farmland. In this model, the loss of nitrogen is primarily determined by the substance (total amount of fertilizer applied), the driving force (precipitation) and the regional environmental conditions (such as topography, soil properties and vegetation cover). The three factors interact with each other and ultimately affect water quality. Therefore, based on the three factors, a comprehensive analysis of the effects of agricultural fertilizer non-point source pollution on water quality can be conducted. The analytical model can be expressed as follows:

$$N_{loss} = f(Fer, Rain, A, U, T) \qquad (1)$$

In Equation 1, N_{loss} represents the amount of nitrogen lost; Fer is the amount of fertilizer applied; rain is the amount of precipitation; A refers to a combination of influential factors such as topographic and geomorphological features, soil type, vegetation cover, crop type and rooting depth, cropping system and fertilizer types; U is the spatial unit, referring to the mode of regional land use; T denotes the time period.

For regional analyses, A and U can be ignored by virtue of the relatively minor variations in the combinations of influential factors, such as topography and geomorphology, soil type, vegetation cover, and the utilization pattern of regional land (Hou et al., 2009). In this case, the model is expressed as:

$$N_{loss} = f(Fer, Rain, T) \qquad (2)$$

Equation 2, is a linear function model, which can be utilized to describe the statistical relationship between nitrogen loss, fertilizer application and precipitation across a large regional scale. In general, the relationship can be described by a univariate function:

$$N_{loss} = \alpha_{Fer,Rain} + \beta_{Fer}Fer + \beta_{Rain}Rain + \beta_{Fer,Rain}Fer \cdot Rain + \varepsilon \quad (3)$$

In Equation 3, $Fer \cdot Rain$ represents the interaction between fertilizer application and precipitation. The statistical relationship between nitrogen losses, fertilizer application and precipitation over a large regional scale can be analyzed through the above univariate function model.

3.2 Model setup

3.2.1 Analysis model of the influence of nitrogen fertilizer loss in farmland on water quality

Jin studied (2014) the influence of precipitation on ammonia nitrogen concentration, taking into account time lag in the process from nitrogen runoff to entry into the water. Lagged terms for precipitation and fertilizer application are incorporated into the "Substance Dynamics Factors" conceptual model of nitrogen loss on farmland. Furthermore, this model can be extended into a dynamic panel model with regional fixed effects to analyze the regional-scale influences.

Based on the above-mentioned research, a model for analyzing the influence of nitrogen fertilizer loss on farmland on water quality can be established as follows:

$$
\begin{aligned}
LnTN_{i,t} = {} & \beta_0 + \beta_1 LnTN_{i,t-1} + \beta_2 Ln\,\alpha FerN_{i,t} + \beta_3 Ln\,\alpha FerN_{i,t-1} \\
& + \beta_4 LnRain_{i,t} + \beta_5 LnRain_{i,t-1} \\
& + \beta_6 (Ln\,\alpha FerN_{i,t} \times LnRain_{i,t}) \\
& + \beta_7 (Ln\,\alpha FerN_{i,t-1} \times LnRain_{i,t-1}) + \theta_i + \varepsilon_{i,t}
\end{aligned}
$$
$$(4)$$

In Equation 4, subscript i represents the monitoring station; subscript t represents time (weeks); $LnTN_{i,t}$ is the dependent variable, which represents the logarithm of the total nitrogen concentration loss at monitoring station i and at time t; $LnTN_{i,t-1}$ represents the logarithm of the total nitrogen concentration in the lagged period; $FerN_{i,t}$ and $FerN_{i,t-1}$ represent the nitrogen fertilizer application for the current and lagged period, respectively; α is the loss coefficient for nitrogen fertilizer loss with runoff; thus $Ln\,\alpha FerN_{i,t}$ and $Ln\,\alpha FerN_{i,t-1}$ represent the logarithm of nitrogen fertilizer loss with runoff for the current and lagged period, respectively; $LnRain_{i,t}$ and $LnRain_{i,t-1}$ represent the logarithm of precipitation for the current and lagged period, respectively; $(Ln\,\alpha FerN_{i,t} \times LnRain_{i,t})$ and $(Ln\,\alpha FerN_{i,t-1} \times LnRain_{i,t-1})$ are the interaction terms between the logarithm of nitrogen fertilizer application loss with runoff and the logarithm of precipitation for the current and lagged period, respectively; θ_i presents the regional fixed effect and $\varepsilon_{i,t}$ is the random error term.

After nitrogen fertilizer applied, the remaining nitrogen, following crops uptake, will be lost through various pathways including leaching, volatilization and runoff. Since this study primarily focuses on runoff loss, it requires the loss coefficient α for nitrogen fertilizer loss with runoff to calculate the loss amount, thereby preventing biased estimation results. The nitrogen fertilizer loss with runoff can be expressed as Equation 5.

$$
\begin{aligned}
& Nitrogen\,fertilizer\,loss\,with\,runoff\,(\alpha FerN) \\
& = Nitrogen\,fertilizer\,applicaation\,(FerN) \times loss\,coefficient \\
& \qquad (\alpha)
\end{aligned}
$$
$$(5)$$

The utilization efficiency of nitrogen fertilizer ranges approximately from 30% to 45% on farmland (Quan et al., 2021; Lin et al., 2007), which implies that the amount of nitrogen fertilizer loss accounts for 55%–70% of the total amount of nitrogen fertilizer application. According to Chen's research (2014), the proportions of nitrogen loss with runoff is approximately 23%.

Loss coefficient (α) is determined by the utilization efficiency of nitrogen fertilizer and the proportion of nitrogen fertilizer loss with runoff as Equation 6.

$$
\begin{aligned}
loss\,coefficient\,(\alpha) = {} & (1 - utilization\,efficiency\,of\,nitrogen\,fertilizer) \\
& \times proportion\,of\,nitrogen\,fertilizer\,loss\,with \\
& \quad runoff\,in\,total\,nitrogen\,fertilizer\,loss \quad (6)
\end{aligned}
$$

As the result, the loss coefficient (α) for runoff ranges from 12.65% to 16.1%.

According to "Bulletin of the Second National Pollution Census of Hainan Province" released by the government of Hainan Province, the total nitrogen fertilizer loss with runoff from agriculture in Hainan Province was 16,369.16 tons in 2017, while

the total nitrogen fertilizer application amounted to 155,700 tons. Therefore, the loss of nitrogen with runoff from farmland accounts for approximately 10.5%. This loss coefficient (α) is relatively close to the estimated range of 12.65%–16.1% mentioned above. Therefore, the loss coefficient (α) for nitrogen fertilizer loss with runoff of 10.5% can be adopted to calculate the total nitrogen fertilizer loss with runoff for each monitoring station.

Pollutants carried by precipitation into rivers represent a primary mode of non-point source pollution; therefore, the precipitation level significantly affects water quality. According to Equation 4, when precipitation exhibits statistical significance and the estimated coefficient is positive, it indicates a carrying effect of the precipitation, and this leads to an increase in total nitrogen concentration. Conversely, when the precipitation exhibits statistical significance and the estimated coefficient is negative, it suggests a dilution effect, and this leads to a reduction in nitrogen concentration.

The statistical significance and positive coefficient for nitrogen fertilizer application, as a source of pollutants, in Equation 4 illustrates that an increase in fertilizer application will have a positive influence on water quality. Since fertilizers need to be carried into the river by precipitation, an interaction term between fertilizer application and precipitation is introduced to verify their combined effect.

Considering the possible time required for nitrogen fertilizer to enter rivers through precipitation, lagged terms for fertilizer application, precipitation and their interaction are added into Equation 4 in order to investigate the influence of lagged precipitation and fertilization on water quality in the subsequent period.

Because of the distinct dry and rainy seasons on Hainan Island, fertilizer application and precipitation during different seasons exert different effects on nitrogen runoff. The accumulation of fertilizers differs between the dry and rainy seasons due to the lower precipitation and longer intervals in the dry season, which results in divergence in the effects of fertilizer application and precipitation on water quality between the dry and rainy seasons. To analyze the influences of fertilizer application and precipitation on total nitrogen concentration during the dry and rainy seasons, DS (dummy variable for dry season) and RS (dummy variable for rainy season) are introduced. By incorporating these dummy variables into the explanatory variables of Equation 4 and forming new interaction terms, nitrogen runoff models for the dry season Equation 7 and the rainy season Equation 8 can be obtained:

$$
\begin{aligned}
Ln\,TN_{i,t} = {} & \beta_0 + \beta_1 \, LnTN_{i,t-1} \\
& + \beta_2 Ln\,\alpha FerN_{i,t} + \beta_3 \left(Ln\,\alpha FerN_{i,t} \times DS_t \right) \\
& + \beta_4 Ln\,\alpha FerN_{i,t-1} + \beta_5 \left(Ln\,\alpha FerN_{i,t-1} \times DS_{t-1} \right) \\
& + \beta_6 LnRain_{i,t} + \beta_7 \left(LnRain_{i,t} \times DS_t \right) + \beta_8 \, LnRain_{i,t-1} \\
& + \beta_9 \left(LnRain_{i,t-1} \times DS_{t-1} \right) \\
& + \beta_{10} \left(Ln\,\alpha FerN_{i,t} \times LnRain_{i,t} \right) \\
& + \beta_{11} \left(Ln\,\alpha FerN_{i,t} \times LnRain_{i,t} \times DS_t \right) \\
& + \beta_{12} \left(Ln\,\alpha FerN_{i,t-1} \times LnRain_{i,t-1} \right) + \beta_{13} \left(Ln\,\alpha FerN_{i,t-1} \right. \\
& \left. \times LnRain_{i,t-1} \times DS_{t-1} \right) + \theta_i + \varepsilon_{i,t}
\end{aligned} \tag{7}
$$

$$
\begin{aligned}
Ln\,TN_{i,t} = {} & \beta_0 + \beta_1 \, LnTN_{i,t-1} \\
& + \beta_2 Ln\,\alpha FerN_{i,t} + \beta_3 \left(Ln\,\alpha FerN_{i,t} \times RS_t \right) \\
& + \beta_4 Ln\,\alpha FerN_{i,t-1} + \beta_5 \left(Ln\,\alpha FerN_{i,t-1} \times RS_{t-1} \right) \\
& + \beta_6 LnRain_{i,t} + \beta_8 \left(LnRain_{i,t} \times RS_t \right) + \beta_7 \, LnRain_{i,t-1} \\
& + \beta_9 \left(LnRain_{i,t-1} \times RS_{t-1} \right) \\
& + \beta_{10} \left(Ln\,\alpha FerN_{i,t} \times LnRain_{i,t} \right) \\
& + \beta_{11} \left(Ln\,\alpha FerN_{i,t} \times LnRain_{i,t} \times RS_t \right) \\
& + \beta_{12} \left(Ln\,\alpha FerN_{i,t-1} \times LnRain_{i,t-1} \right) + \beta_{13} \left(Ln\,\alpha FerN_{i,t-1} \right. \\
& \left. \times LnRain_{i,t-1} \times RS_{t-1} \right) + \theta_i + \varepsilon_{i,t}
\end{aligned} \tag{8}
$$

In this model, all variables in the equations have been logarithmically transformed, which allows for a clearer expression of the influence of the change rate of fertilizer application and precipitation on the change rate of total nitrogen concentration.

Table 2 shows the definitions and descriptive statistics of each variable used in the model.

3.2.2 Model of the influence of planting structure on nitrogen fertilizer loss

The material basis for the loss of nitrogen fertilizer in farmland is the regional planting structure. The total amount of fertilizer applied varies across different regions due to the influence of planting structure, and this subsequently affects the quantity of pollutant loss. On the basis of studies by Liang et al. (2013) and Min et al. (2020) regarding the influence of planting structure on fertilizer application and loss, the following model is established to analyze the influence of planting structure on nitrogen loss:

$$
\begin{aligned}
LnY_{i,t} = {} & \beta_0 + \beta_1 LnPCSA_{i,t} + \beta_2 LnGSA_{i,t} + \beta_3 LnCSA_{i,t} + \beta_4 LnTSA_{i,t} \\
& + \beta_5 LnIGFerN_{i,t} + \beta_6 LnICFerN_{i,t} + \beta_7 LnITFerN_{i,t} + \theta_{i,t} \\
& + \varepsilon_{i,t}
\end{aligned} \tag{9}
$$

In Equation 9, subscript i represents the monitoring station; subscript t represents time (weeks); the dependent variable LnY_i represents the logarithm of total nitrogen loss; the core explanatory variable $LnPCFerN_i$ represents the logarithm of the proportion of sown area occupied by cash crops. The rest of the variables are the control variables: $LnGSA_{i,t}$, $LnCSA_{i,t}$ and $LnTSA_{i,t}$ represent the logarithm of sown area occupied by grain crops, cash crops and tropical crops, respectively; $LnIGFerN_{i,t}$, $LnICFerN_{i,t}$ and $LnICFerN_{i,t}$ represent the logarithms of nitrogen fertilization intensity for grain crops, cash crops and tropical crops, respectively.

In the model, all variables in the equations have been logarithmically transformed, which allows for a clearer expression of the influence of the change rate of each variable on the change rate of total nitrogen loss. Table 3 shows the definitions and descriptive statistics of each variable in the model.

3.3 Estimation method

A lagged term of total nitrogen concentration has been incorporated into the model assessing the influence of nitrogen fertilizer runoff from farmland on water quality, which means that the explanatory variables in the model now include lagged terms of the dependent variables, thus

TABLE 2 Definitions and descriptive statistics of model variables related to the influence of nitrogen fertilizer loss in farmland on water quality.

Variables	Definition	N	Mean	SD	Min	Max
TN	Total nitrogen concentration in the watersheds of monitoring stations ($mg \cdot L^{-1}$)	1,404	1.396	0.694	0.219	5.579
Rain	Weekly precipitation in the watersheds of monitoring stations (mm)	1,404	32.61	50.16	0.0376	578.5
α FerN	Weekly nitrogen fertilizer loss with runoff in the watersheds of monitoring stations (tons)	1,404	9.698	12.27	0.181	93.64
DS	Dummy variable indicating whether it is the dry season (1 for dry season, 0 otherwise)	1,404	0.462	0.499	0	1
RS	Dummy variable indicating whether it is the rainy season (1 for rainy season, 0 otherwise)	1,404	0.538	0.499	0	1

TABLE 3 Definitions and descriptive statistics of model variables related to the influence of planting structure on nitrogen loss.

Variables	Definition	N	Mean	SD	Min	Max
Y	Total nitrogen loss in the watersheds of monitoring stations (tons)	1,404	26.43	70.62	0.0715	870.3
PCSA	Proportion of sown area occupied by cash crops in the watersheds of monitoring stations (%)	1,404	0.313	0.168	0.0413	0.809
GSA	Sown area occupied by grain crops planting in the watersheds of monitoring stations (hectares)	1,404	365.0	446.2	0	1,645
CSA	Sown area occupied by cash crops planting in the watersheds of monitoring stations (hectares)	1,404	1,818	1,877	40.77	7,997
TSA	Sown area occupied by tropical crops planting in the watersheds of monitoring stations (hectares)	1,404	3,373	2,958	270.1	12,518
IGFerN	Fertilization intensity for grain crops in the watersheds of monitoring stations ($kg \cdot ha^{-1}$)	1,404	88.92	311.7	0	3,892
ICFerN	Fertilization intensity for cash crops in the watersheds of monitoring stations ($kg \cdot ha^{-1}$)	1,404	87.10	202.5	0.177	1,931
ITFerN	Fertilization intensity for tropical crops in the watersheds of monitoring stations ($kg \cdot ha^{-1}$)	1,404	15.46	25.00	0	171.9

introducing a correlation between the dependent variables and the random error terms. Meanwhile, for a long dynamic panel dataset where the number of time series (52 weeks in total) exceeds the number of monitoring points (27 in total), using Generalized Method of Moments (GMM) for estimation might result in significant biases.

Kivet et al. (1999), through Monte Carlo simulation analysis, found that for long panels, the estimates yielded by the Bias-Corrected Least Square Dummy Variable Model (LSDVC) were significantly superior to those from the Difference GMM and System GMM. The LSDVC model was capable of correcting over 90% of the biases. Therefore, this study utilizes the LSDVC model for its estimations based on the Difference GMM estimator proposed by Arellano-Bond. Simultaneously, a comparative analysis is conducted using OLS regression and a Fixed Effects model. Although OLS regression and the Fixed Effects model may present biases in estimating dynamic panel data, their results respectively indicate the upper and lower bounds of true estimates for the dependent variables' lagged terms. Thus, the present paper presents the estimations produced by OLS regression and the Fixed Effects model for comparison.

The model regarding the influence of planting structure on nitrogen loss is based on panel data. Therefore, the Fixed Effects model is utilized to estimate the coefficients of explanatory variables.

4 Results

4.1 Influence of agricultural nitrogen fertilizer loss on water quality

In this section, we analyze the influence of nitrogen fertilizer application and precipitation on the total nitrogen concentration in

rivers across Hainan Island. Furthermore, we estimate whether there are variations between the dry season and the rainy season. The results are presented in Tables 4, 5.

Table 4 shows the regression results of the model for the influence of agricultural nitrogen fertilizer loss on water quality. In Model (1), the lagged total nitrogen concentration is statistically significant at the 1% level, indicating the cumulative nature of pollutants. An increase in the total nitrogen concentration in the previous period significantly raises the concentration of total nitrogen in the current period. The influence of current precipitation on total nitrogen concentration is statistically significant at the 1% level, with an estimated coefficient of 0.0556. The lagged precipitation is statistically significant at the 5% level, with an estimated coefficient of −0.0181. Neither current nor lagged fertilizer application are statistically significant. However, the interaction term between lagged precipitation and lagged nitrogen fertilizer application is statistically significant at the 5% level, with an estimated coefficient of 0.0101.

The regression results elucidate the static relationship between the effects of precipitation and fertilizer application on total nitrogen concentration.

Firstly, precipitation on Hainan Island plays a dual role in influencing water quality by both carrying effect and diluting effect. In most simulated rainfall experiments, rainfall intensity has been identified as a significant factor influencing the losses of nitrogen and phosphorus (Song et al., 2017). The elevation of rainfall intensity in these experiments is associated with overall increases in total nitrogen losses (Wu et al., 2018). In this study, through the analysis of current precipitation on Hainan Island, it has been found that current precipitation has a carrying effect on nitrogen loss. Specifically, for every 1% increase in current precipitation, the total

TABLE 4 Regression results of the influence of agricultural nitrogen fertilizer loss on water quality Models.

Variables	Model (1)	Model (2)	Model (3)
	LSDVC	Fixed effects	OLS
$LnTN_{i,t-1}$	0.815***	0.783***	0.858***
	(0.0155)	(0.0165)	(0.0165)
$Ln\,\alpha FerN_{i,t}$	−0.00472	−0.00823	0.00347
	(0.0186)	(0.0203)	(0.0195)
$Ln\,\alpha FerN_{i,t-1}$	−0.0122	−0.0152	−0.0260
	(0.0166)	(0.0203)	(0.0186)
$LnRain_{i,t}$	0.0556***	0.0553***	0.0589***
	(0.00823)	(0.00885)	(0.00873)
$LnRain_{i,t-1}$	−0.0181**	−0.0156*	−0.0168*
	(0.00843)	(0.00927)	(0.00885)
$Ln\,\alpha FerN_{i,t} \times LnRain_{i,t}$	−0.00354	−0.00305	−0.00318
	(0.00415)	(0.00428)	(0.00413)
$Ln\,\alpha FerN_{i,t-1} \times LnRain_{i,t-1}$	0.0101**	0.0108**	0.00970**
	(0.00433)	(0.00439)	(0.00396)
Constant		−0.0484*	−0.0662***
		(0.0264)	(0.0208)
Observations	1,377	1,377	1,377
R-squared		0.686	0.811

Standard errors in parentheses ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

nitrogen concentration in rivers increases by 0.0542%. In addition, some studies have also shown that as runoff flow increases, the dilution effect tends to reduce nitrogen concentration. In Yang et al. (2009) study on the influence of precipitation on nitrogen and phosphorus loss in the Sichuan Basin, it was found that precipitation has a dilution effect on the concentration of NO₃-N in the flow, and the concentration decreases with the increase flow before increasing with the decrease in flow. Girolamo et al. (2020) simulation results for the southern watershed of Sardinia Island also show that the concentration of nitrogen decreased in accordance with the flow, and increased with a decrease in flow. In the present study, the lagged precipitation on Hainan Island exhibits a diluting effect on water quality. For each 1% increase in the lagged precipitation, there is a decrease of 0.014% in the total nitrogen concentration in rivers. The above findings indicate that precipitation on Hainan Island plays a dual role in the quality of water bodies.

Secondly, the fertilization practices of farmers on Hainan Island significantly impact water quality; however, this influence exhibits a lag effect. Some studies indicate that within 8 days after the application of nitrogen fertilizer, initial surface runoff events significantly increase the nitrogen concentration (Cui et al., 2020), and nitrogen concentration reaches higher levels within 7–10 days after fertilization, and gradually decreases thereafter (Xue et al., 2014). Based on the results of this study, it can be

observed that the influence of nitrogen fertilizer application on water quality also demonstrates a lagged effect. For the nitrogen fertilizer loss induced by precipitation, each 1% increase in the lagged application of nitrogen fertilizer leads to a 0.0101% increase in total nitrogen concentration.

To validate the credibility of the LSDVC regression results, the estimated coefficients of the LSDVC method for the lagged terms of the dependent variable should lie between those of the fixed effects model and OLS regression. Model (2) and Model (3) correspond to the estimation results of the fixed effects model and OLS regression, respectively. The results from both models are statistically significant at the 1% level, and the estimated coefficients are positive. For the lagged term of total nitrogen concentration, the estimated coefficient in the fixed effects model is 0.783, representing the lower limit. In the OLS regression model, the estimated coefficient is 0.858, representing the upper limit. The LSDVC method's estimated coefficient for the lagged total nitrogen concentration is statistically significant at the 1% level, with the value of 0.815. It falls within the credible interval between the upper and lower limits, indicating that the LSDVC method provides reliable estimates for total nitrogen concentration.

Table 5 presents the regression results of the influence models for nitrogen fertilizer loss in farmland on water quality during the dry season (Model 4) and the rainy season (Model 5). In the model of the dry season (Model 4), the interaction term between current precipitation and the dummy variable for the dry season is statistically significant at the 10% level, with an estimated coefficient of 0.000577. Moreover, the interaction terms between lagged nitrogen fertilizer application, lagged precipitation and the dummy variable for the dry season are statistically significant at the 5% level, with coefficients of 0.0114.

On the other hand, in the model of the rainy season (Model 5), the interaction term between current precipitation and the dummy variable for the rainy season is statistically significant at the 1% level, with an estimated coefficient of 0.000711. Meanwhile, the estimates for the interaction terms between lagged nitrogen fertilizer application, lagged precipitation and the dummy variable for the rainy season are statistically significant at the 10% level, with coefficients of −0.00998.

Figure 3 presents the weekly average total nitrogen concentration, precipitation and nitrogen fertilizer application data for all monitoring stations. It can be observed that there are noticeable seasonal variations on the island, with pronounced differences in precipitation between the dry season and the rainy season, the total nitrogen concentration in the rivers exhibits a V-shaped variation trend throughout the year and The variations in nitrogen fertilizer application are correlated with the planting season, and show two distinct peaks.

As shown in the figure, the influence of precipitation and fertilization on water quality in Hainan Island exhibit dynamic correlations. The estimation results of the dry season model (Model 4) and the wet season model (Model 5) further illustrate the dynamic relationship between these factors. It can be observed that the influence of precipitation and fertilization on total nitrogen concentration in rivers on Hainan Island exhibit significant differences between the dry and rain seasons. During the dry season, the longer intervals between precipitation allow for greater accumulation of fertilizer in agricultural fields compared

TABLE 5 LSDVC regression results of the influence of agricultural nitrogen fertilizer loss on water quality models in dry and rainy season.

Variables	Model (4)	Model (5)
	Dry season	Rainy season
$LnTN_{i,t-1}$	0.803***	0.804***
	(0.0155)	(0.0154)
$Ln\,\alpha FerN_{i,t}$	−0.0257	−0.00789
	(0.0199)	(0.0201)
$Ln\,\alpha FerN_{i,t} \times DS_t$	0.000290*	
	(0.000151)	
$Ln\,\alpha FerN_{i,t} \times RS_t$		−0.000129
		(0.000152)
$Ln\,\alpha FerN_{i,t-1}$	−0.0157	−0.0182
	(0.0180)	(0.0181)
$Ln\,\alpha FerN_{i,t-1} \times DS_{t-1}$	0.000093	
	(0.000142)	
$Ln\,\alpha FerN_{i,t-1} \times RS_{t-1}$		0.0000696
		(0.000160)
$LnRain_{i,t}$	0.0482***	0.0446***
	(0.00887)	(0.00884)
$LnRain_{i,t} \times DS_t$	0.000577*	
	(0.000329)	
$LnRain_{i,t} \times RS_t$		0.000711***
		(0.000168)
$LnRain_{i,t-1}$	−0.0160*	−0.0186**
	(0.00853)	(0.00910)
$LnRain_{i,t-1} \times DS_{t-1}$	−0.000361	
	(0.000479)	
$LnRain_{i,t-1} \times RS_{t-1}$		−0.000231
		(0.000203)
$Ln\,\alpha FerN_{i,t} \times LnRain_{i,t}$	0.00632	0.0000759
	(0.00485)	(0.00431)
$Ln\,\alpha FerN_{i,t} \times LnRain_{i,t} \times DS_t$	−0.00912**	
	(0.00420)	
$Ln\,\alpha FerN_{i,t} \times LnRain_{i,t} \times RS_t$		−0.00162
		(0.00436)
$Ln\,\alpha FerN_{i,t-1} \times LnRain_{i,t-1}$	0.00829*	0.0211***
	(0.00486)	(0.00510)
$LnF\alpha erN_{i,t-1} \times LnRain_{i,t-1} \times DS_{t-1}$	0.0114**	
	(0.00463)	
$Ln\,\alpha FerN_{i,t-1} \times LnRain_{i,t-1} \times RS_{t-1}$		−0.00998**

(Continued in next column)

TABLE 5 (*Continued*) LSDVC regression results of the influence of agricultural nitrogen fertilizer loss on water quality models in dry and rainy season.

Variables	Model (4)	Model (5)
	Dry season	Rainy season
		(0.00482)
Observations	1,377	1,377

Standard errors in parentheses ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

to the rainy season. Consequently, with the same amount of precipitation, the carrying effect of precipitation is stronger in the dry season, resulting in greater nitrogen runoff into rivers and a greater impact on total nitrogen concentration. However, since the amount and frequency of precipitation are lower in the dry season compared to the rainy season, the dilution effect of lagged precipitation on total nitrogen concentration is relatively weaker.

4.2 Influence of planting structure on nitrogen loss

The regression results of the model assessing the influences of nitrogen fertilizer loss on water quality reveal significant effects of agricultural fertilization activities on total nitrogen pollution. Considering the potential influence of changes in planting structure on the total amount of fertilization, this section focuses on estimating the influence of planting structure on nitrogen loss, with nitrogen loss as the dependent variable and the proportion of sown area allocated for cash crops as the core explanatory variable. The estimated results are presented in Table 6.

From the estimation results, the R-squared value of 0.535 shown in Table 6 indicates that the model can account for 53.5% of the variance in total nitrogen loss. The proportion of sown area allocated for cash crops is statistically significant at the 1% level, with an estimated coefficient of 3.595, indicating that planting structure is one of the main factors affecting nitrogen loss. When the proportion of sown area allocated for cash crops with high fertilizer application but low utilization efficiency increases, the amount of nitrogen loss in the watersheds will also rises. Specifically, for each 1% increase in the proportion of sown area allocated for cash crops, the nitrogen loss increases by 3.595%.

The results indicate that the planting structure on Hainan Island significantly affects the nitrogen loss. As the proportion of sown area allocated for cash crops increases, which are characterized by high fertilizer application and low utilization efficiency, nitrogen loss in the watersheds also rises. Specifically, for each 1% increase in the sown area allocated for cash crops, nitrogen loss increases by 3.595%. Additionally, the estimated results show that a 1% increase in the fertilization intensity of cash crops leads to a 0.326% increase in total nitrogen loss in the watersheds. In contrast, the production activities of grain crops and tropical crops have a relatively smaller influence on nitrogen runoff.

Based on existing research, from the perspective of land use, indicated that land use and land cover can affect the phosphorus output (Recanatesi et al., 2013) and there is significant variation in the total nitrogen output per unit area of farmlands allocated for
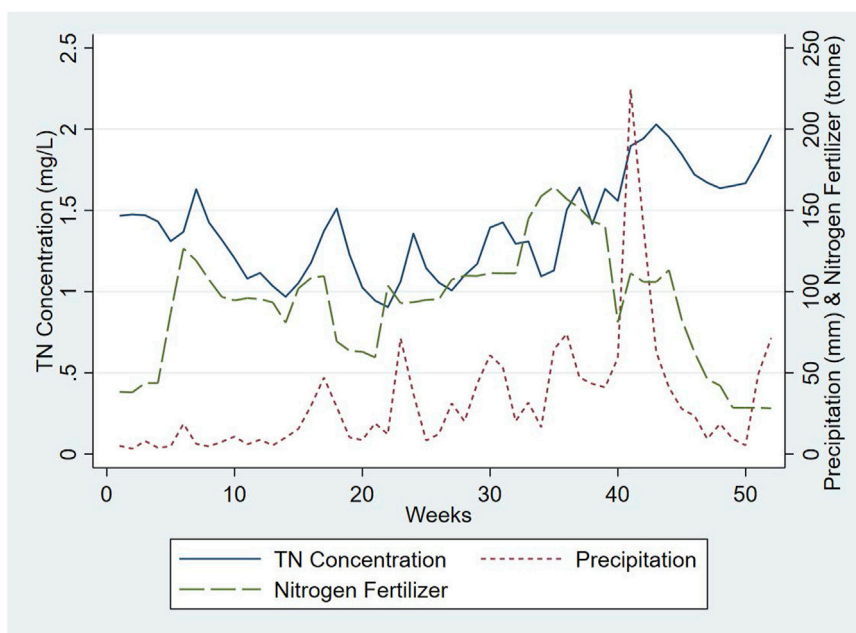
FIGURE 3
Weekly average precipitation, fertilizer application and total nitrogen concentration in Hainan Island in 2021.

crops such as sugarcane, rice and rubber (Yang et al., 2011). From the perspective of fertilizer utilization efficiency in crops, the demands for nitrogen fertilizer and its utilization efficiency vary among different crop type, resulting in differences in nitrogen runoff among different crops on Hainan Island. Therefore, for agricultural production activities on Hainan Island, the cultivation of cash crops significantly impacts nitrogen runoff, while the influence of grain crops and tropical crops is relatively smaller. Consequently, the total nitrogen runoff on Hainan Island is expected to increase with a higher proportion of cash crop cultivation and greater fertilizer application intensity.

5 Conclusion and policy implications

5.1 Conclusion

This study investigated the effects of fertilization and precipitation on the total nitrogen concentration in rivers on Hainan Island, and extends the total nitrogen loss model by introducing lag terms, dummy variables and interaction terms for the dry and rainy seasons. The influences of fertilization and precipitation on river nitrogen concentration at different time periods (current and lagged) as well as during different seasons (dry and rainy) are analyzed, and the dynamic correlation between agricultural production activities and non-point source pollution is explored. Additionally, the relationship between planting structure and non-point source pollutant loss is investigated, highlighting the significant differences between the effects of various crop types on pollutant loss. The results indicate that the proportion of planting area

TABLE 6 Regression results of influence of planting structure on nitrogen loss.

Variables	Model (6)
	Fixed effects
PCFerN	3.595***
	(0.901)
GSA	−0.0264
	(0.0259)
CSA	1.081
	(0.785)
TSA	−0.735
	(1.257)
IGFerN	0.0372
	(0.0308)
ICFerN	0.326***
	(0.0662)
ITFerN	−0.135
	(0.104)
Constant	4.342
	(7.249)
Observations	1,404
R-squared	0.535

Standard errors in parentheses ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

allocated for economic crops and fertilizer intensity significantly influences pollutant losses, while the influences of food crops and tropical crops are less pronounced.

Compared to previous literature, this study utilizes weekly data from 27 monitoring stations on Hainan Island in 2021, providing accurate and detailed information on composition of water pollution. This dataset addresses the scarcity of direct observational data on agricultural non-point source pollution. Methodologically, this study incorporates precipitation as an exogenous factor, considering its mediating effect in the entry of non-point source pollutants into water bodies. Additionally, it includes lagged and interaction terms to examine the effects of precipitation and fertilization on water quality. This method addresses the shortcomings of insufficient detailed regional data on agricultural non-point source pollutants and transforms the static relationship of pollution influence into a dynamic one, resulting in more accurate results. It helps in analyzing the contribution of agricultural non-point source pollution to water pollution and provides reliable references for sustainable agricultural development.

5.2 Policy implications

The results of this study offer significant policy guidance for the prevention and control of agricultural non-point source pollution. The recommendations are as follows:

(1) Adopt advanced technologies for reducing fertilizer application, such as soil testing, slow-release fertilizers, precision fertilization techniques and the utilization of organic fertilizers. Implement scientific and rational fertilization management, improve nutrient utilization efficiency and minimize negative externalities associated with excessive fertilizer application on the environment.

(2) Strengthen collaboration between agricultural regulatory authorities and meteorological departments in Hainan Province to develop scientific and rational guidelines for the planting periods and structures of cash crops. Such guidelines should be tailored based on local rainfall and temperature conditions in order to be better adapted to climate changes and enhance the efficiency of agricultural production. Agricultural regulatory authorities can also access real-time meteorological data to assist farmers in formulating more precise fertilization plans, reducing fertilization application before precipitation, and minimizing nutrient loss during rainy periods.

(3) It is crucial to reinforce water resource management policies, such as by establishing effective isolation facilities between rivers and irrigation channels, including diversion embankments, barriers or other physical obstacles, to control the amount of irrigation or precipitation drainage from farmland. Such measures would not only reduce the likelihood of nitrogen elements flowing into rivers, but would also facilitate the reuse of nitrogen-containing water resources, thereby improving nitrogen fertilizer utilization rates and minimizing the adverse environmental impacts of nitrogen loss.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

SW: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing–original draft, Writing–review and editing. SZ: Conceptualization, Investigation, Methodology, Resources, Validation, Writing–review and editing.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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