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Influence of Chemical Element Pollution on Ecological Farmland Environment Based on the Overlay and Index Method

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The pollution of chemical elements to farmland soils and agricultural production has become one of the hot issues in the existing study of soil chemistry and agricultural environmental pollution. It is of great practical significance to strengthen the study of chemical elements on farmland soil pollution for promoting the safe and healthy development of agricultural production. To this end, this paper adopts the overlay and index method to evaluate the influence of chemical elements on the soil environment of the farmland by taking the nitrogen as an example. The results show that nitrogen exists in different soil layers in various forms, e.g., for the nitrate nitrogen, its content in the soil gradually increased with time, and that in the lower root zone was the highest, at the highest growth rate; that of the intermediate unsaturated zone was the lowest. The pollution of chemical elements on farmland soil is divided into natural factors and human factors. The overlay and index method-based index system was established to obtain the comprehensive index of chemical elements on soil environmental pollution of ecological farmland. The research results can provide theoretical reference and scientific basis for pollution prevention and control of farmland.

1. Introduction

China is a big agricultural country. With the development of national economy, the safety of agricultural production has become one of the most important issues for the public. However, following the continuous advancement of industrialization, in the farmland ecosystem, a large number of chemical elements flow into the farmland soil with irrigation water, and through migration, transformation, enrichment and accumulation in the soil, it has an impact on the safety of agricultural production, causing damage to human health. Therefore, the pollution of chemical elements to farmland soils, farmland and even human health has become one of the hot issues in the study of soil chemistry and agricultural environmental pollution (Drayson and Thompson, 2013; Zhan et al., 2018). It is of great significance to strengthen the study of chemical elements of farmland soil pollution for promoting the safety and health of agricultural production (Fretzer, 2016).

At present, for the problem of chemical elements polluting the ecological farmland environment, many experts and scholars at home and abroad have conducted a lot of research and formed many fruitful research results. Some scholars have studied the evaluation methods of chemical element pollution in soil (De et al., 2006; Hill, and Arnold, 2012); some scholars conducted research about the influence degree of chemical elements on farmland environment (Aryafar et al., 2013; Yuan et al., 2007); also, some other scholars have studied the consequences caused by the chemically contaminated farmland environments (Canals et al., 2007). Mainly based on the overlay and index method, this paper evaluates the influence of chemical elements on farmland soil environment by taking nitrogen as an example. This shall provide scientific basis for farmland pollution prevention and control, and have important practical significance for agricultural production safety.

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2. Overlay and index method

2.1 Establishment of index system

The overlay and index method is mainly to make overlays by the sub-index of the selected evaluation parameters and then form a comprehensive index reflecting the degree of vulnerability, which can systematically analyse the characteristics of agricultural activities and the influence factors. This method can be divided into Hydrogeologic complex setting methods (HCS) and parameter system method. Among them, the HCS method mainly compares the vulnerability of known areas with that of the research area, which is usually qualitative analysis and evaluation. The parameter system method is mainly to establish a parameter system; each parameter has a certain value range that can be divided into several intervals, and each interval gives the corresponding score value or vulnerability (i.e., the scoring standard of parameter level) so as to compare the actual data of each parameter with this standard; finally, the scores obtained by the parameters are overlaid, to obtain the comprehensive index.
In this study, the index system of the overlay and index method is mainly composed of natural factor indicators and agricultural factor indicators.

2.2 Natural factor

The medium type and thickness of the soil, the slope of the terrain, and the depth of the groundwater level all have a certain impact on the pollution caused by chemical elements. Different soil media and thickness will have different degrees of influence on the attenuation (adsorption, oxidation, volatilization, reduction, biodegradation, etc.) of chemical pollutants. The slope of the terrain mainly affects the runoff and infiltration of surface water, which determines whether chemical pollutants will flow with surface runoff or permeate into the bottom of the soil (Caniani et al., 2016).
The burial depth of groundwater level mainly indicates the vertical distance between the upper surface layer of the aquifer and the ground. It determines the distance from the chemical pollutants to the aquifer and also the time of contact with the surrounding soil. In addition, it also determines that the chemical pollutants contacts with the oxygen in the soil interstitial water, so as to make oxidation reaction.

2.3 Agricultural factor

The farmland soil contains a large number of chemical elements. Figure 1 shows the specific gravity of the chemical elements in the soil. In this paper, by taking nitrogen as an example, the influences of agricultural factors were studied in terms of fertilization amount and fertilization type.

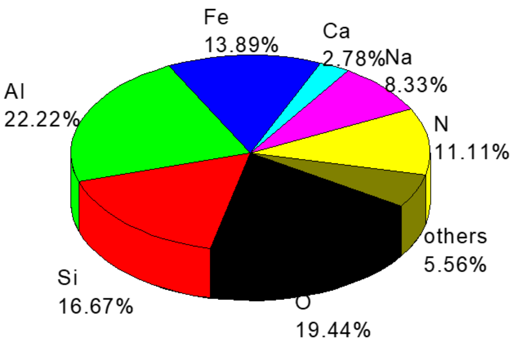

Figure 1: Proportion of Main Elements in Farmland

Fertilizers contain a large amount of nitrogen, and fertilization of farmland soils will increase the nitrogen content of the soil. Relevant research shows that if the nitrogen application rate of each season crop exceeds 113.7Kg/hm^2, vast residual nitrate nitrogen will accumulate, and also the more fertilizer is applied, the more nitrate nitrogen accumulates. If the nitrogen application rate per season is less than 74.5 Kg/hm^2, no residual accumulation of nitrate nitrogen will occur. Table 1 lists the nitrogen application rate of the main crops in agricultural production activities.
Different types of nitrogen fertilizers also have large differences in leaching amount. The leaching of ammonium nitrate is usually the highest and that of organic fertilizer is the lowest. Table 2 mainly lists the classification of common nitrogen fertilizers.

Table 1: Nitrogen requirement and fertilizer application of major crops

Crops	Nitrogen requirement of crops			Fertilizer application			Yield per
	N	P	K	N	P	K	mu(kg)
Wheat	3.2	1.31	2.43	13-16	7-8	7-8	450
Rice	2.7	1.19	3.18	11-14	5-7	4-7	520
Corn	2.61	1.27	4.06	9-12	4.3-6.2	6-7	520
Peanut	5.19	1.04	2.37	3.7-5.9	2.1-3.5	6.5-9.8	450
Soybean	8.34	1.82	3.55	0.5-3.5	6.2-8.4	4-9	280

Table 2: Classification of common fertilizers

Type	Common nitrogen fertilizer
Ammonium nitrogen fertilizer	Ammonium sulfate, ammonium chloride, ammonium bicarbonate
Nitrate nitrogen fertilizer	Sodium nitrate and calcium nitrate
Ammonium nitrate nitrogen fertilizer	Ammonium nitrate, calcium ammonium nitrate, ammonium thiosulfate
Amide nitrogen fertilizer	Urea, calcium cyanamide

In addition, irrigation, precipitation and farming methods all also have a certain impact on the pollution of chemical elements to the farmland soil environment.

3. Influence of chemical element pollution on the ecological farmland environment

3.1 Changes of nitrogen concentration in soil

In this paper, selecting the farmland soil in the central part of Heilongjiang Province as the sample, the nitrogen in the soil was studied. The soil layer is divided into an upper root zone, a lower root zone, and an intermediate unsaturated zone. Nitrogen exists in different soil layers in a variety of forms. Taking nitrate nitrogen as an example, its quality change in each layer of soil is shown in Figure 2.

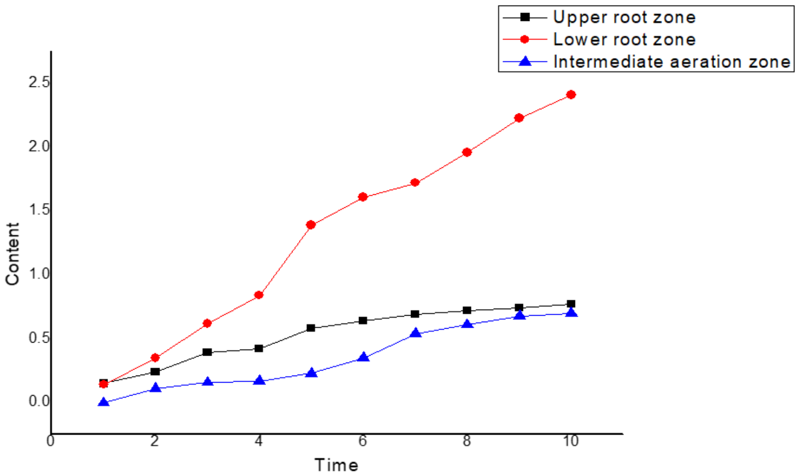

Figure 2: The change of nitrate nitrogen quality in soil layers with time

From the data in Figure 2, it can be found that the content of nitrate nitrogen gradually increased with time; the lower root zone had the highest content of nitrate nitrogen, at the fastest growth rate; in the upper root zone, the nitrate nitrogen content first reached an equilibrium state; the intermediate unsaturated zone had the lowest nitrate nitrogen content.

3.2 Scoring of influence factors

The overlay and index method is very similar to the DRASTIC model in the design and scoring of influence factors. Therefore, based on the scoring standard of DRASTIC model, the scores of relevant factors indicators were obtained in this paper by some slight adjustment. Table 3-5 list the numerical range of each influence factor and the corresponding specific score value.

Table 3: Scoring of soil media

Media type	Thin layer or missing	Sand	Expansive clay	Sandy loam	Loam	Silty loam	Clay loam	Non - expansive clay
Score	10	9	7	6	5	4	3	1

Table 4: Scoring of terrain slope

Terrain slope	T≤2	2<T≤6	6<T≤10	10<T≤14	T≥14
Score	10	9	6	4	2

Table 5: Fertilizer Index Scoring Table

Fertilizing amount	Score	Nitrogen fertilizer type	Score	Fertilization mode	Score
0-2.5	1	nitramine	10	Deep fertilization	10
2.5-5.0	2	Ammonium sulfate	8	Shallow fertilization	8
5.0-7.0	3	Urea	6	Surface fertilization	6
7.0-10.0	4	Ammonium bicarbonate	5	Uniform fertilization	3
10.0-12.5	5	chloramine	3	Surface fertilization of stems and leaves	1
12.5-15.0	6	Organic fertilizer	1		
15.0-17.5	7				
17.5-20.0	8				
20.0-22.5	9				
>22.5	10				

3.3 Determining the weight of the influence factors

In terms of natural factors, the determination of index weights is mainly based on the weight distribution of the DRASTIC model, as shown in Table 6. However, if applied to soil research, it will be affected by other external factors, such as pH value, soil adsorption of nitrogen, and organic matter content, etc. The index weights need to be finely adjusted (Table 7).

Table 6: Weight of evaluation factors

Evaluation factor	D	R	A	S	T	I	C
weight	5	4	3	2	1	5	3

Table 7: The weight of the adjusted evaluation factor

Evaluation factor	D	R	A	S	T	I	C
weight	5	2	3	2	1	3	1

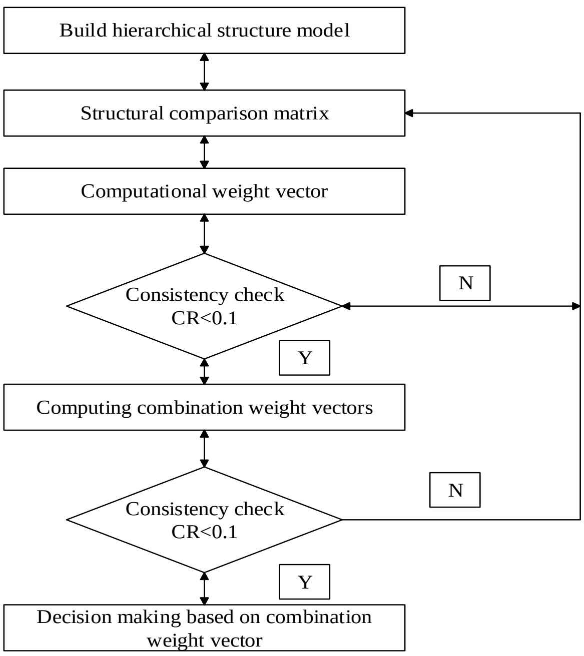

Figure 3: Analytic Hierarchy Process Flow Chart

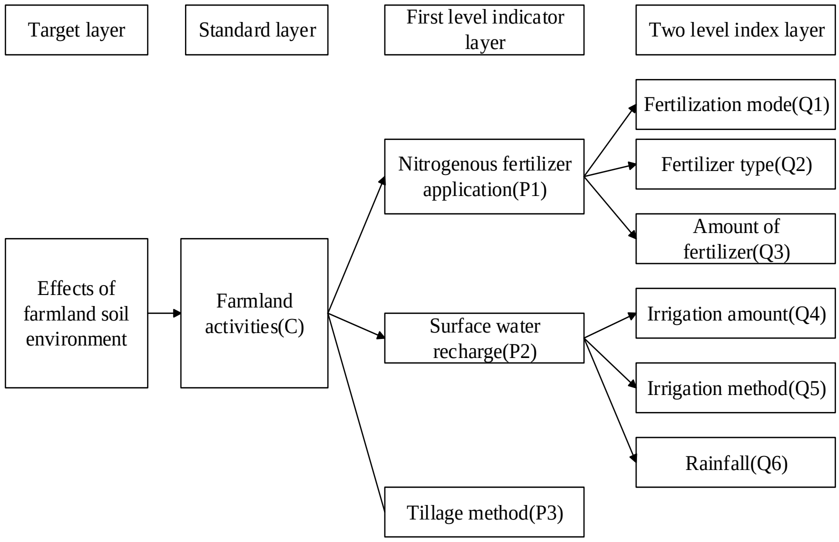

Figure 4: Hierarchical model

In terms of agricultural factors, the index weights are mainly determined based on the analytic hierarchy process (AHP). It is processed through a combination of quantitative and qualitative analysis. The most important is the confirmation of the hierarchy and the establishment of the judgment matrix. Figure 3 shows the specific process. Figure 4 depicts the hierarchical structure model established in this paper. Based on this, the judgment matrix was constructed accordingly.
According to the judgment matrix, the maximum eigenvalue and the eigenvector can be obtained. Then, by normalizing the eigenvector, the sequenced weight vector of the hierarchical unit can be obtained, to derive the consistency index CI and the randomness consistency ratio CR. It's calculated as:

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n-1} \quad (1)$$

$$\mathrm{CR} = \frac{\mathrm{CR}}{\mathrm{RI}} \quad (2)$$

The value range of RI is shown in Table 8.

Table 8: Value table of RI

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14
RI	0	0	0.61	0.87	1.23	1.31	1.38	1.42	1.49	1.53	1.55	1.56	1.57	1.59

If the CR is greater than 0.1, it means that it fails in the consistency test and the re-adjustment needs to be made. If the CR is less than 0.1, the consistency test is passed, and the obtained weight value is valid. Then, the weight distribution can be made, as shown in Table 9.

Table 9: Farmland characteristic index weight

	Fertilization（P1）	Irrigation（P2）	Farming（P3）
Weight	0.61	0.31	0.08
Inspection	λ_{max}=3.12 CI=0.04 CR=0.06<0.1		
	Fertilization mode(Q1)	Fertilizer types(Q2)	fertilizing amount(Q3)
Weight	0.09	0.22	0.69
Inspection	λ_{max}=3.04 CI=0.05 CR=0.08<0.1		
	Irrigation volume(Q4)	Irrigation mode(Q5)	Rainfall(Q6)
Weight	0.29	0.07	0.64
Inspection	λ_{max}=3.12 CI=0.04 CR=0.06<0.1		

In order to facilitate the data statistics and the final calculation, the four indicators of farming methods, irrigation methods, fertilization types and fertilization modes were combined together in this paper, which are collectively referred to as management indicators of farmland soil. The obtained final weights were: fertilization amount is 0.51, irrigation amount is 0.11, farmland soil management is 0.22, and rainfall is 0.16.

Meanwhile, based on the weight distribution in the DRASTIC model, the weights obtained by the AHP were transformed to conclude the final result: the fertilization amount is 6, the farmland management is 3, the rainfall is 2, and the irrigation amount is 1.

3.4 Comprehensive index evaluation model

The comprehensive index CRI of chemical elements pollution to the ecological farmland soil was calculated by multiplying the scores of the various indicators by the weights, and finally summing them up. The obtained range of value is about 62-273. It's calculated as:

$$\mathrm{CRI} = \sum W_{ni} \cdot P_{ni} + \sum W_{ai} \cdot P_{ai} \quad (3)$$

where, W_{ni} and P_{ni} respectively are the weights and scores of various indicators for natural factors; W_{ai} and P_{ai} respectively are the weights and scores of various indicators for agricultural factors.
Finally, according to the scores, the pollution risk of chemical elements on the farmland soil environment was classified into six grades (Table 10).

Table 10: Classification of farmland soil environmental pollution risk

Extremely low risk	Very low risk	Lower risk	Higher risk	High risk	Extremely High risk
<70	70-130	130-170	170-230	230-260	>260

4. Conclusions

(1) Nitrogen exists in various forms in different soil layers. Taking nitrate nitrogen as an example, its content in soil showed a trend of increasing with time; the content of lower root region was the highest at the highest growth rate; in the upper root zone, the content first reached equilibrium; the intermediate unsaturated zone had the lowest content.
(2) The pollution of chemical elements on farmland soil is divided into natural factors and human factors. The overlay and index method-based index system was also established to obtain the comprehensive index of chemical elements on soil environmental pollution of ecological farmland, and the range of values was calculated to be about 62-273.

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