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Effects of long-term cultivation on spatial-temporal variation of soil nitrogen and phosphorus: a case study in Shaanxi Province, China

Jing Cao · Yiping Chen · Hong Wang · Yao Jiang · Junhua Wu

Abstract Investigating the spatial-temporal variation of soil nitrogen (N) and phosphorus (P) is essential to determine the balance between increased food production and environmental protection. In this study, a total of 705 soil samples were collected at depths of 0–20 cm in 2017 and analyzed for laboratory tests of soil N and P. The results showed that from the 1980s to 2017, the total nitrogen (TN), available nitrogen (AN), and available phosphorus (AP) contents of farmland soils in Shaanxi Province increased by 33%, 17%, and 199%, respectively, while the total phosphorus (TP) content decreased by 40%. The best-fit model for spatial interpolation of soil TP and AP in Shaanxi Province was the exponential model ($R^2 = 0.92$ and 0.95); the Gaussian model was the best-fit model for spatial interpolation of soil TN and AN ($R^2 = 0.98$ and 0.96). The spatial distribution characteristics of soil TN, AN, TP, and AP were consistent, all being higher in southern Shaanxi than in northern Shaanxi. The value of N:P* ratio (molar ratio) of cultivated soils in Shaanxi Province is 2.9, which is lower than the Chinese average (N:P* = 5.0). Based on the spatial-temporal variations of soil N and P contents between regions, it is recommended that fertilization should be strictly controlled in central and southern Shaanxi and optimized in northern Shaanxi to improve ground strength.

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Introduction

As one of the most important ecosystems in the world, farmland provided two-thirds of the world's grain supply (Yin et al., 2006). Currently, China feeds 22% of the world's population on 9% of the world's arable land (Shen et al., 2018). From 1980 to 2020, the amount of fertilizer applied to farmland increased by nearly 4×10^8 kg in China; more chemical fertilizers, pesticides, and agricultural films had been used in pursuit of higher grain yields and to meet the needs of a growing population (Ding et al., 2023). The current state of fatigued farmland caused an average fertilizer utilization rate of 40.2% for China's three main food crops, which is 10–20% lower than those of developed countries such as Europe and the USA in 2020 (Zhang, 2021). In addition, excessive input of

agricultural chemicals increases the ecological risk of agricultural non-point source pollution and even the health risk to human beings. The results of the Second National Pollution Source Census show that agricultural activities are an important source of nitrogen (N) and phosphorus (P) pollution, accounting for 46.5% and 67.2% of total domestic emissions, respectively (Liu et al., 2020). Therefore, it is imperative to focus on nutrient management in China's farmland ecosystems to avoid fertilizer waste and environmental risks.

Soil N and P are important indicators of soil fertility and quality, playing an essential role in nutrient cycling and promoting plant growth in the agricultural ecosystem (Gao et al., 2015; Sistla & Schimel, 2012; Zhang et al., 2011). In general, soil TN and TP are commonly used to evaluate soil fertility, and soil AN and AP are closely related to crop growth (Zhao et al., 2007). Structural factors and stochastic factors jointly affect the variation of soil N and P contents (Zhong et al., 2020; Zhu et al., 2018), and geostatistical analysis is widely used to reveal the spatial heterogeneity in soil nutrients (Chen et al., 2016; Momtaz et al., 2016). Meanwhile, soil N and P in agroecosystems have significant spatial heterogeneity compared to other terrestrial ecosystems because agroecosystems are more susceptible to human activities (Muñoz-Rojas et al., 2015; Pereira et al., 2013; Zhang et al., 2018). As the basis of studying variations in nutrient structure, biodiversity, and geochemical cycles, soil N:P ratio can more comprehensively describe the variability of soil N and P (Smith, 1992; Elser et al., 1996). However, it is not difficult to find that most previous studies have focused on the distribution of the N:P ratio of the natural ecosystem of forest and grassland, with fewer conducted to explore that of farmland ecosystem (Liu et al., 2010; Ren et al., 2007; Wu et al., 2010).

Shaanxi Province is located in Northwest China, the birthplace of ancient Chinese agriculture, where the application of fertilizer has been increasing annually, yet the yield ranks at the bottom of the list in China (Wang, 2020). Most of the reported studies are focused on local areas in Shaanxi Province, and there is an absence of research on the spatial-temporal variation of soil N and P on a macro-provincial scale, which is not conducive to scientifically guiding the rational fertilization of farmland soils across the region. Model-based on GIS and geostatistics, we

are committed to (1) revealing the temporal variation characteristics of soil N and P from the 1980s to 2017 in Shaanxi Province; (2) mapping provincial spatial heterogeneity of soil N and P; and (3) revealing the N and P grading characteristics and evaluating the N:P ratio in Shaanxi Province. This study is expected to provide a theoretical basis for balancing fertilizer and food security, which is conducive to sustainable agricultural development in Northwest China and even semi-arid areas.

Materials and methods

Study site

Shaanxi Province is located in the hinterland of China, lying in a range from 31°42′N to 39°35′N and from 105°29′E to 111°15′E, with a total area of 205.6 million km², a length of 880 km, and a width of 160–490 km. Since the topography of Shaanxi Province is high in the north and south and low in the middle, the province is divided into the Northern Shaanxi Plateau (SB), the Guanzhong Plain (GZ), and Southern Shaanxi Mountainous Area (SN). The total area of SB accounts for about 40% of the total land area of the province, with an elevation of 900–1900 m. The total area of GZ is 49.4 million km², with an elevation of 460–850 m, and the total area of SN is about 36% of the total land area of the province, with an elevation of 1000–3000 m. There is a great difference in climate between the north and south of Shaanxi Province. SN has a north subtropical climate; most of GZ and SB have a warm temperate climate, while SB has a middle temperate climate along the Great Wall. The annual average temperature of the province is 9–16 °C, increasing from north to south and from west to east. The annual average precipitation is 340–1240 mm, with more precipitation in the south than in the north. The area of SN is humid; the area of GZ is semi-humid, and the area of SB was semi-arid. The soil in the province is divided into 9 soil types, 22 soil classes, 49 subclasses, 134 soil genera, and 403 soil species. The main soil types are chestnut soil, black loessial soil, brown soil, yellow brown soil, aeolian sandy soil, loess soil, paddy soil, Chao soil, newly accumulated soil, marsh soil, and saline-alkali soil. The distribution pattern of the zones is obvious, with the chestnut-calcium soil-dark loessial soil zone in

SB, the brown earths-cinnamon soil zone in GZ, and the yellow-brown earths-yellow-cinnamon soil zone in SN.

Soil sampling

A total of 705 soil samples were collected from farmland in Shaanxi Province in 2017 based on the spatial distribution of the site (Fig. 1), including 258 samples from the northern Shaanxi Plateau, 210 samples from Guanzhong Plain, and 237 samples from the southern Shaanxi mountain. The sampling distance was 10 km, and 0–20 cm topsoil was collected according to the five-point method using a 5-cm diameter stainless steel corer. The soil samples were mixed and brought back to the laboratory.

Analyses of soil properties

In this study, the soil TN was determined by the Kjeldahl method after the digestion in H_2SO_4 (Bremner & Mulvaney, 1982), and soil AN was measured by the alkali-hydrolyzed reduction diffusing method. Soil TP was determined by the Mo-Sb colorimetric method after digestion in H_2SO_4-$HClO_4$ (Parkinson & Allen, 1975), and soil AP was determined using Olsen's method after extraction with $NaHCO_3$ (Olsen, 1954). The data on soil available potassium and pH in Shaanxi Province were quoted from the literature (Cao et al., 2021; Wang & Cao, 2021). DEM data and administrative division data came from the cloud platform of geographical national conditions monitoring (http://www.dsac.cn). Date on elevation, slope, and aspect were extracted from DEM data.
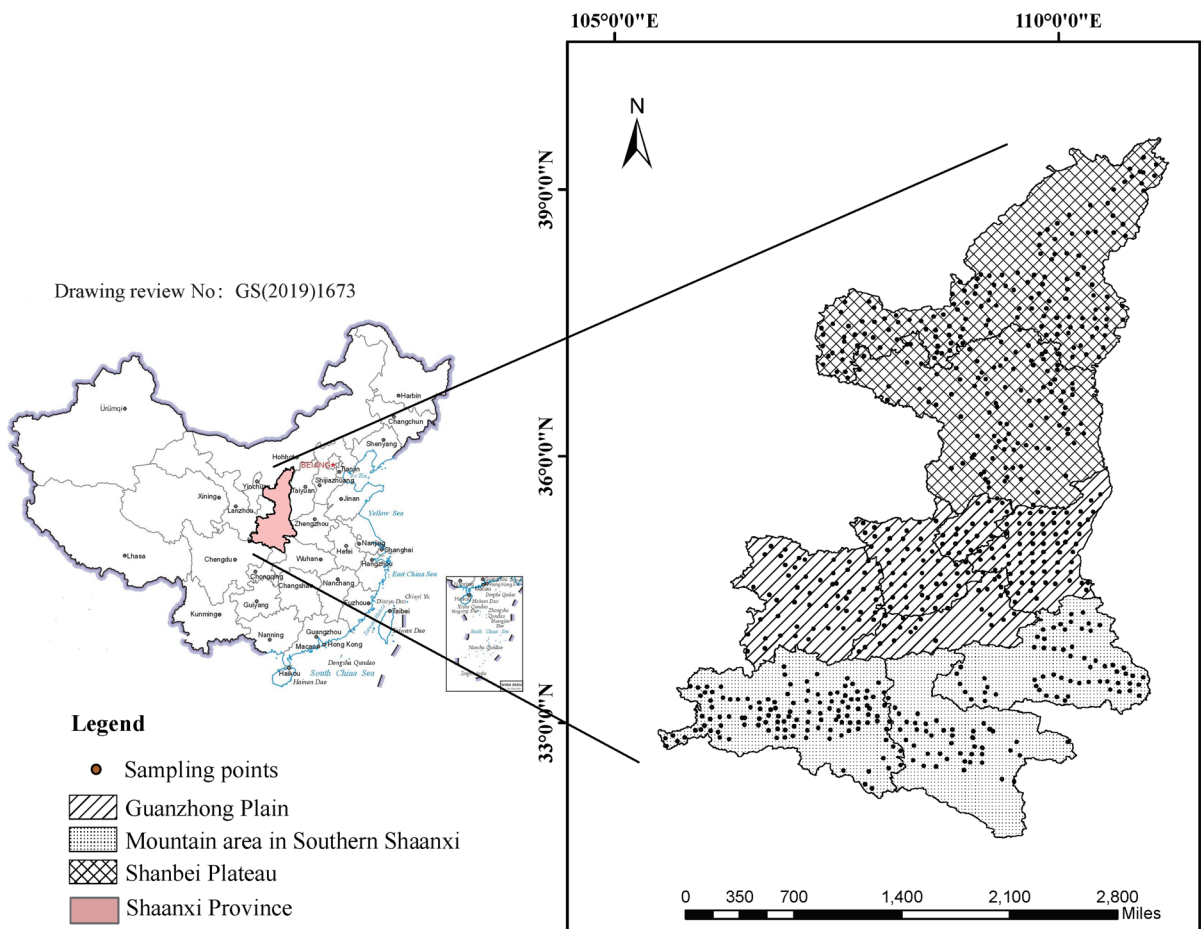

Fig. 1 Location of the study region and sampling points

Statistical analyses

The Shapiro-Wilk test was used to verify the normality of the data, and logarithmic transformations were performed on data with unequal variances that were not normally distributed. One-way ANOVA (Tukey HSD and Dunnett T3 tests) was used to analyze the correlation between soil N and P and the influencing factors at the significance level of < 0.05. Pearson correlation analysis and principal component analysis were used to analyze the correlation between soil N and P and the influencing factors. Data analysis was performed using IBM SPSS22.0 software. Excel 2016 was used for routine statistical analysis. GS+9.0 was used to obtain the optimal fitting theoretical model of soil N and P in Shaanxi Province. Global Moran index was used for spatial autocorrelation analysis; spatial interpolation analysis used the Ordinary Kriging method, and both were performed by ArcGIS10.2 using the Geostatistical Analyst package. Graphing was performed using OriginPro 9.1 and ArcGIS10.2 software.

The Moran index was used to measure the spatial autocorrelation of adjacent observations of a variable (Moran, 1948). Moran's I ranges from −1 to +1, where −1 is strongly negative spatial autocorrelation, 0 is the random pattern, and +1 is strongly positive spatial autocorrelation. Spatial autocorrelation was significant at the significance level of < 0.05 and which could be expressed as:

$$I = \frac{n \sum \sum Z_i Z_j}{\sum Z_i^2} \tag{1}$$

where n was the number of positions, $Z_i = X_i - \overline{X}$, and $Z_j = X_j - \overline{X}$.

Semivariogram was determined to characterize the appropriate model function that was fit to the semivariogram. The ratio $[C_0/(C_0 + C)]$ was used to calculate the spatial dependence of soil properties. If the ratio is < 25%, the variable had strong spatial dependence. If the ratio was between 25 and 75%, the variable had moderate spatial dependence. And if the ratio is > 75%, the variable had weak spatial dependence (Cambardella et al., 1994). The formula for semivariogram $\gamma(h)$ was:

$$\gamma(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} \left(Z_i - Z_{(i+h)}\right)^2 \tag{2}$$

where Z_i and $Z_{(i+h)}$ were the measured value for the variables at locations X_i or $X_{(i+h)}$, h was the distance between sample points, and $n(h)$ was the number of pairs at distance h (Burgess & Webster, 1980).

Kriging interpolation is used to predict the size of unknown points by the size of known sample points. The common Kriging interpolation based on the theory of variation function and structural analysis could fully consider the spatial variation of soil characteristics. The formula was

$$Z(x_0) = \sum_{i=1}^{n} \lambda_i Z(x_i) \tag{3}$$

where $Z(x_0)$ was the value of unknown point, $Z(x_i)$ was the value of known point, n was the number of known sample points, and λ_i was the weight.

The soil total N and P contents (g kg^{-1}) could be converted into mmol kg^{-1} by the following formula:

$$N : P^* = N : P \times (31/14) \tag{4}$$

Results

Temporal variation of soil N and P

Compared with the 1980s, the average contents of TN, AN, and AP in farmland soils in Shaanxi Province increased by 33%, 17%, and 199% in 2017, respectively, while the soil TP content decreased by 40% (Fig. 2). Among the cities, soil AP and AN contents have increased significantly in Baoji, Weinan, and Xianyang since the 1980s (Fig. 2c and d), with the largest increase in soil TN content in Xi'an (Fig. 2a). Furthermore, soil TP contents in Ankang, Yan'an, and Tongchuan have decreased by more than 50% in the past nearly four decades (Fig. 2b). The order of soil TN and AN contents in 2017 in each natural region of Shaanxi Province was SN > GZ > SB, and the order of soil TP and AP contents was GZ > SN > SB. The ranking of soil TP, TN, and AN contents in each natural zone in the 1980s was consistent with that in 2017. At the city scale, it was easy to find that soil TN and AN contents in Yan'an, Yulin, Tongchuan, and Weinan were lower than the provincial average level in 2017. And soil N content fluctuated more than soil P content among cities because soil N content was basically off the average, while soil P content was close to the average. In addition, the trends in soil TN and AN contents were generally consistent across cities, while the trends in soil TP and AP contents were generally consistent (Fig. 2).
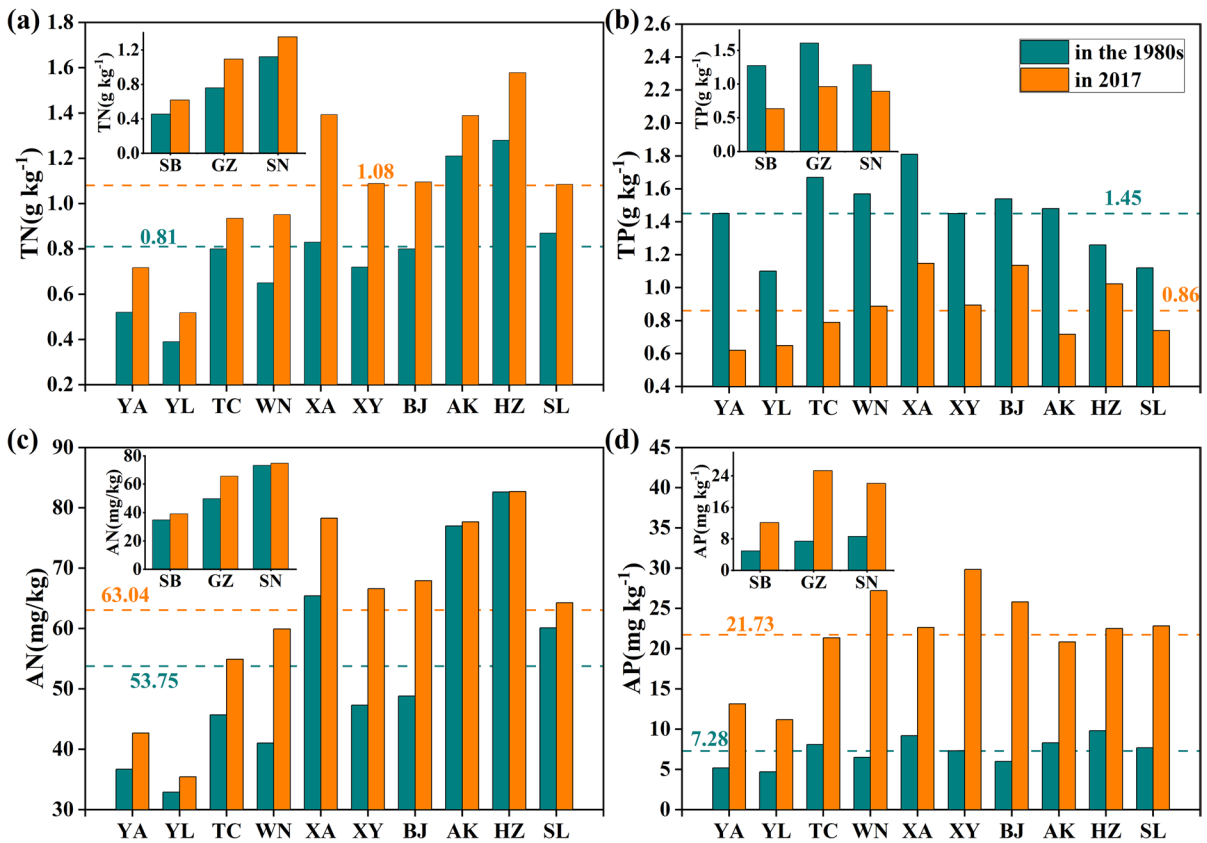
Fig. 2 Temporal variation of soil TN (**a**), TP (**b**), AN (**c**), and AP (**d**) content in Shaanxi Province. Notes: The dotted line represents the average nutrient level of ten cities in Shaanxi Province. The abbreviation are as follow: YA, Yan'an; YL, Yulin; TC, Tongchuan; WN, Weinan; XA, Xi'an; XY, Xianyang; BJ, Baoji; AK, Ankang; HZ, Hanzhong; SL, Shangluo; SB, Northern Shaanxi; GZ, Guanzhong; SN, Southern Shaanxi

Spatial variations of soil N and P

Spatial autocorrelation of variables as a prerequisite for geostatistical interpolation is shown in Fig. 3. Test of soil N and P autocorrelation in Shaanxi Province indicated that Z values of soil TN, TP, AN, and AP contents in Shaanxi Province were 59.76, 31.26, 51.10, and 28.03, and the corresponding probability P was lower than 0.01, respectively, showing strong spatial aggregation. Furthermore, Moran's index of
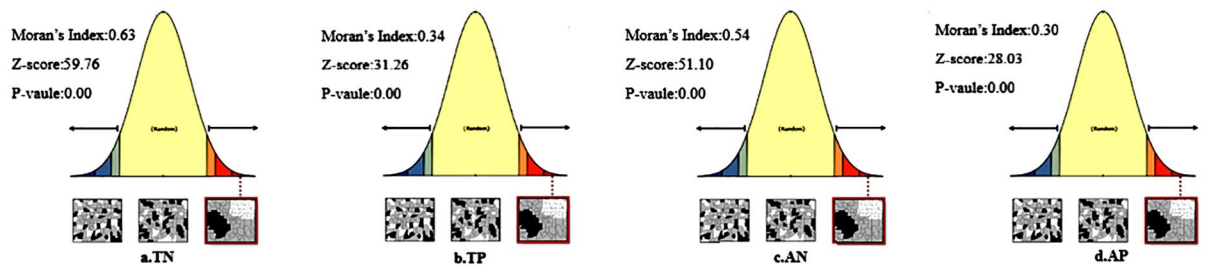

Fig. 3 Test of soil N and P autocorrelation in Shaanxi Province

soil TN, TP, AN, and AP in Shaanxi Province was greater than 0, indicating that the soil TN, TP, and AP in Shaanxi Province were positively correlated. All these showed that soil N and P in Shaanxi can meet the preconditions for geostatistical interpolation (Fig. 3).

Normal distribution as the premise of geostatistical analysis is shown in Table 1. Soil TN and AN were by normal distribution by the K-S test, while soil TP and AP were satisfied after logarithmic transformation. Geostatistics takes the second-order stationary hypothesis as another premise, and uses the semivariance function model to describe its spatial variation (Fig.4). The optimal fitting model of soil TN and AN content in Shaanxi Province was the Gaussian model; the exponential model was most suitable for soil TP and AP in Shaanxi Province. The fit coefficients (R^2) of soil TN, TP, AN, and AP were close to 1, indicating that the models were well-fitted. The nugget coefficients of soil TN and AN were both higher than 75%, indicating that the spatial correlation was weak and the variables were mainly influenced by random factors, while the nugget coefficients of TP and AP were between 25 and 75%, indicating that the variables had a moderate spatial correlation and were influenced by both structural and random factors.

The farmland soil AN content in Shaanxi Province had a pattern of spatial distribution that was similar to that of soil TN, which showed that the soil TN and AN were concentrated in the southwest and part of the central areas of the Shaanxi Province, with the lowest in the northern part (Fig. 5a and c). In addition, soil AP and TP contents were greatest in central Shaanxi Province (Fig. 5b and d), with soil TP contents exceeding 1.1 g kg^{-1} in Baoji, Xi'an, and Weinan, and soil AP contents exceeding 22 mg kg^{-1} in GZ and SN. Overall, the spatial distribution patterns of TN, AN, TP, and AP all showed a similar distribution characteristic that the soil TN, TP, AN, and AP contents in Shaanxi Province were higher in the south than those in the north (Fig. 5).

According to the classification standard of the second soil census, as far as Northern Shaanxi is concerned, Yulin City has the largest proportion of soil TN at level 6 with 58%, while Yan'an City has the largest proportion of soil TN at level 5. For the GZ region, Tongchuan and Weinan have the highest proportion of soil TN at level 4, while Xi'an and Baoji have the highest proportion of soil TN at level 3. Concerning the Southern Shaanxi region, Ankang and Shangluo had the largest proportion of soil TN at level 3 (Fig. 6a). Ankang and Yan'an had the largest proportion of soil TP content at level 4; Xianyang, Yulin, and Shangluo had the largest proportion of soil TP content at level 3; Tongchuan and Weinan had the largest proportion of soil TP content at level 2, and Xi'an, Baoji, and Hanzhong had the largest proportion of soil TP content at level 1 (Fig. 6b). Yan'an, Yulin, Tongchuan, and Weinan had the largest proportion of soil AN at level 5, while the other

Table 1 Semivariogram models and relative parameters of soil N and P in Shaanxi Province

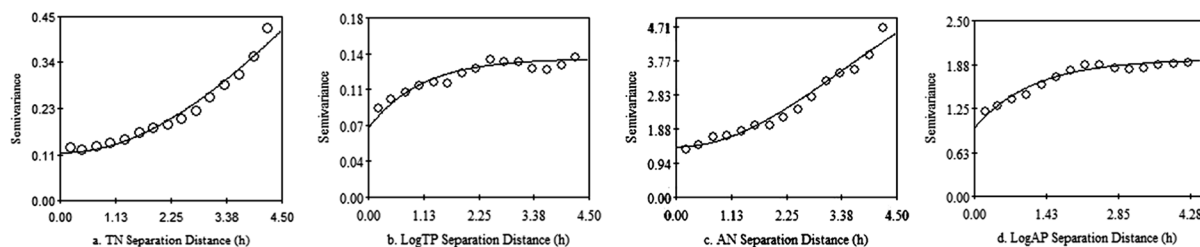| Index	Model	C_0	$C_0 + C$	$C/(C_0 + C)$	Range	Residual SS	R^2
TN	Guassian	0.117	1.319	0.911	14.52	2.842E-03	0.975
LogTP	Exponential	0.069	0.139	0.504	3.2	3.877E-04	0.917
AN	Guassian	1.390	6.789	0.795	8.35	0.496	0.955
LogAP	Exponential	0.974	1.949	0.500	3.53	0.0424	0.952

Fig. 4 Semivariogram models of soil N and P in Shaanxi Province
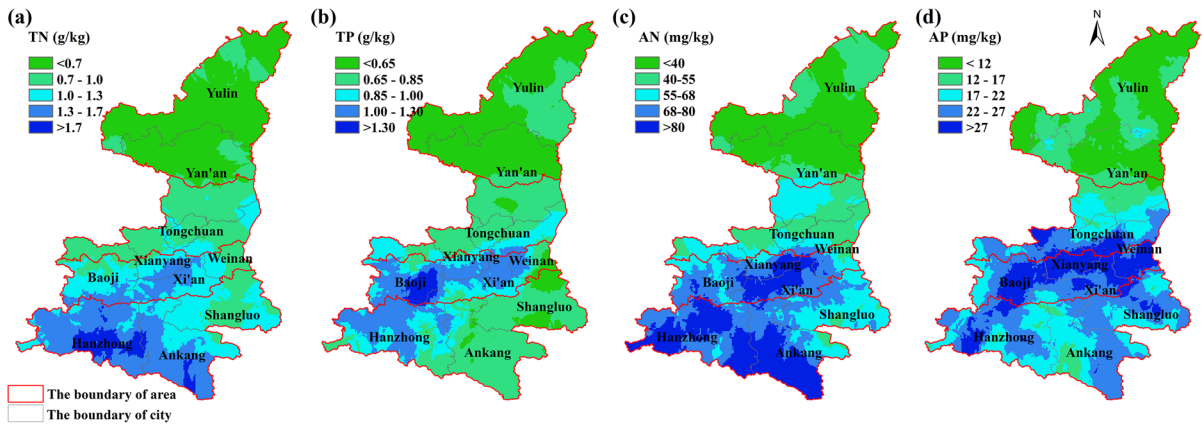
Fig. 5 Spatial variation of soil TN (**a**), TP (**b**), AN (**c**), and AP (**d**) in Shaanxi Province
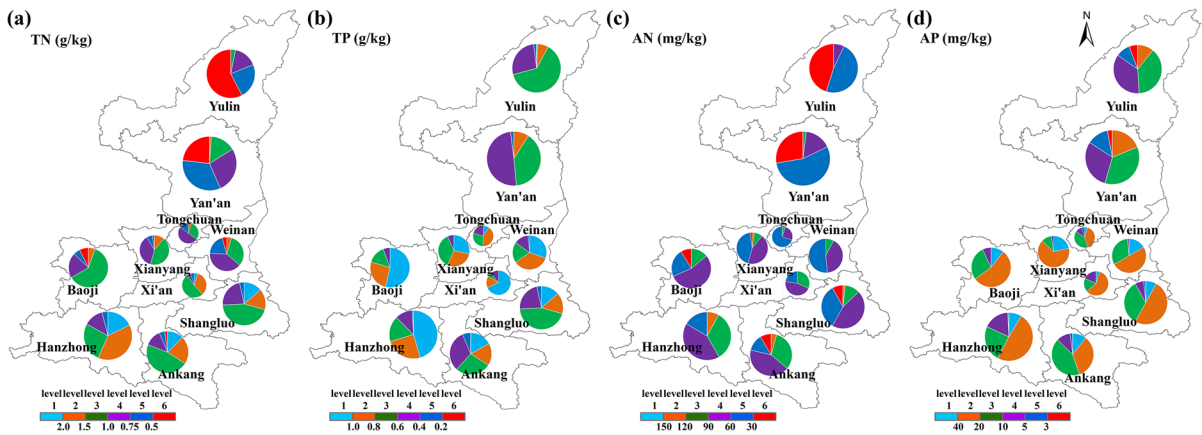

Fig. 6 Classification characteristics of soil TN (**a**), TP (**b**), AN (**c**), and AP (**d**) in Shaanxi Province

cities had the largest proportion of soil AN at level 4 (Fig. 6c). Ankang, Yan'an, and Yulin had the largest proportion of soil AP content at level 3, while the other cities had the largest proportion of soil AP content at level 2 (Fig. 6d).

Soil N:P ratio and the influencing factors

The soil N:P* ratio of farmland in cities in Shaanxi Province did not reach the average level in China (N:P* = 5.0), and soil N:P* ratio of cities in SN was higher than the average level in Shaanxi Province, while those in GZ and SB were lower than the average level in Shaanxi Province. The ANOVA results showed that the soil N:P* ratio in SN was significantly higher than that in GZ and SB; the soil N:P*

ratio in Yulin in SB was significantly lower than that in Yan'an, and there was no significant difference in the soil N:P* ratio among cities in GZ ($P < 0.05$). The soil N:P* ratio in Ankang was the highest, while that in Yulin was the lowest, which even reached less than 2.0. In addition, the soil N:P* ratio of all cities in the GZ region ranged from 2.0 to 3.0, while the soil N:P* ratio of all cities in the SN region exceeded 3.0 (Fig. 7). From Figure 8, it could be concluded that Soil N:P ratio had a significant positive correlation with soil SOM, TN, and AN content, while a significant negative correlation with soil pH and TP content ($P < 0.05$). Soil TN, TP, AN, SOM, and AP contents were significantly positively correlated and were significantly negatively correlated with pH. Among the topographical factors, longitude, latitude, and altitude

Fig. 7 Characteristics of soil N:P* in Shaanxi Province. The points (means) with different letters are significantly different at the $P < 0.05$ level. Notes: the blue dotted line represents the average level of soil N:P* in Shaanxi Province, while the red dotted line represents the average level of soil N:P* in China
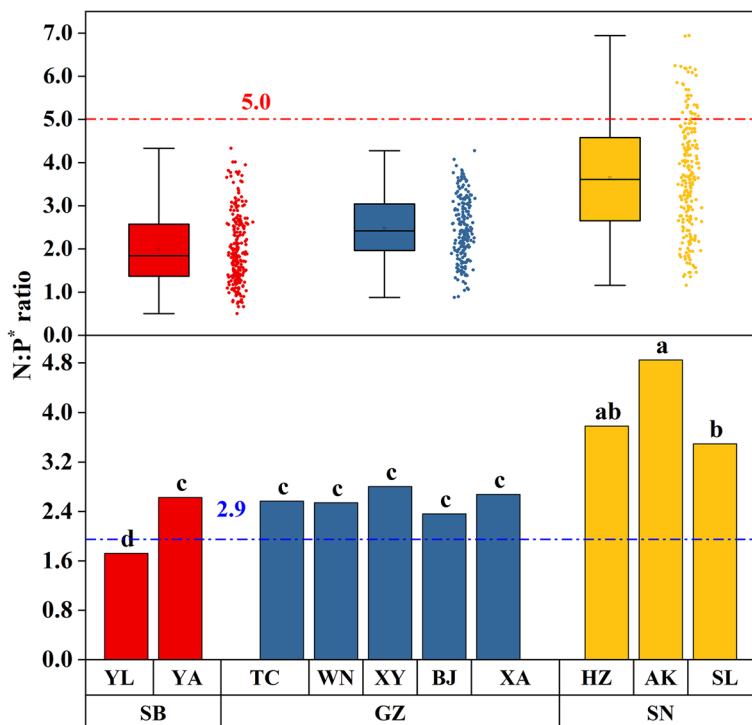
were closely related to soil nutrients ($P < 0.05$), except for slope and aspect ratio, indicating that soil N and P contents were significantly influenced by topographical factors.

Four principal components were further identified using the PCA method, explaining most of the variation between all variables in the soil index (Fig. 8). In addition to the eigenvalues and commonalities, the results of loading factors for four maximum rotations show that there are three eigenvalues > 1, which together explain 63.08% of the total variance. The first principal component explained 40.6 % of the total variance and loaded heavily on TN (0.40), SOM (0.40), AN (0.37), and pH (−0.34), representing the level of fertility of the soil parent material. The second component was dominated by AK (0.55), AP (0.35), and slope (0.52), and accounted for 13.0% of the total variance, representing the level of chemical fertilizer application. Lastly, the third component was dominated by altitude (−0.44), longitude (0.53), aspect (0.54), slope (0.82), and TP (0.47) and accounted for 9.4% of the variance, representing the topographic factor. In addition, soil fertility in all three regions was closely correlated with PC1 and showed that soil nitrogen levels were

higher in SN, at an average level in GZ, and lower in SB, consistent with the spatial distribution pattern of soil nitrogen and phosphorus in Shaanxi Province, which was high in the south and low in the north. In addition, the correlation between soil fertility and PC2 was greater in GZ, indicating that soil fertility in this region was more influenced by the amount of fertilizer applied (Fig. 8).

Discussion

Temporal variation of soil N and P

Temporal variations of soil N and P in Shaanxi Province were observed for the first time in our study. Over the past four decades, the farmland soil AP content in Shaanxi Province increased, while the soil TP content decreased (Fig. 2b and d). Similar temporal variations in soil P decline were observed in other ecosystems, such as intensive vegetable production systems (Shi et al., 2018; Yan et al., 2013) and cultivated land in Shaanxi Province (Wu et al., 2019). Since the 1980s, phosphate fertilizer was popularized instead of farmyard fertilizer and chemical nitrogen fertilizer in
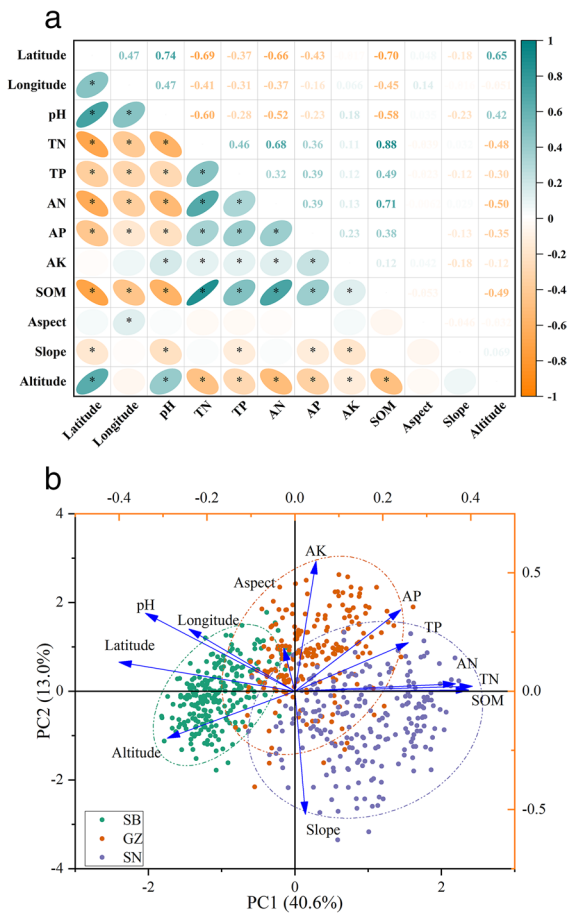
Fig. 8 The correlation and principal component analysis of the soil N, P, and the influencing factors. Notes: *Represents the variables are significantly correlated at the 0.05 level

research of other agricultural regions in China (Chen et al., 2018; Luo et al., 2016; Zhao et al., 2015), indicating the widespread enrichment of nitrogen in farmland soil in China. The increase in fertilizer application, straw returning, and organic fertilizer application could explain this temporal variation. Firstly, the amount of nitrogen applied to cultivated land in Shaanxi Province is continuously increasing. It was reported that the amount of chemical fertilizer used in Shaanxi Province in 2017 was nearly eight times higher than in the 1980s (Yan et al., 2013), which increased the nitrogen content in cultivated soil. Secondly, the straw return was promoted vigorously, and the planting area of green fertilizer was greatly increased in Shaanxi Province, and organic nitrogen in straw is an essential source of soil nitrogen (Yu et al., 2021). In addition, emphasis on the application of organic fertilizer has also improved soil fertility to some extent (Zhu & Jin, 2013).

Spatial variations of soil N and P

Clarifying the spatial variations of soil N and P contents is helpful to manage farmland for accurate fertilizer application. The combination of stochastic factors including topography, cropping pattern, cultivation, the fertilizer application method, land use history, and structural factors including soil organic matter, soil texture, and soil moisture characteristics resulted in a high degree of spatial heterogeneity of soil N and P contents in farmland (Deiss et al., 2017; Zhou et al., 2021; Zhu et al., 2021). In this study, soil N and P contents in Shaanxi Province have strong spatial heterogeneity, with higher soil N and P contents in Hanzhong, Ankang, Xi'an, Baoji, and Xianyang (Fig. 5), which is attributed to the higher level of modernization and intensive production in these areas. And soil N and P contents in Yan'an are significantly higher than those in Yulin, which is consistent with the previous findings (Wang, 2020), and we attribute this to the high inputs of fertilizers caused by the massive planting of fruit trees in Yan'an. Furthermore, the soil TN, AN, TP, and AP in Shaanxi Province gradually increased from north to south, which can be attributed to differences of soil parent material, climatic conditions, soil physical and chemical properties, and topographic factors in Shaanxi Province. And the rule is consistent with the gradual thinning of soil texture, the gradual decline of soil pH, the gradual warming and humidity

Shaanxi Province. With the declining benefits of years of phosphorus application alone, compound fertilizers have been promoted since 2004. Soil nutrients continue to be exported as crop yield increases, and the imbalance of soil phosphorus depletion leads to a decrease in soil TP content. Therefore, we attribute this temporal variation of P to the change in fertilization structure and crop yield improvement in Shaanxi Province. The increase in soil AP is not contradictory to the decrease in soil TP because of the low bioavailability of soil P and is associated mainly with an increase in the amount of effective phosphorus fertilizer applied in recent years.

The nitrogen nutrient levels of farmland soil in Shaanxi Province have increased in recent 30 years (Fig. 2a and c), which is consistent with the reported

of climatic conditions, and the improvement of cultivation and fertilization levels from north to south in Shaanxi Province. Similar studies at the provincial scale have been carried out, for example, Chen et al. (2018) found that the spatial distribution of N status in topsoil was characterized by being high in the east and low in the west in Jilin Province, and Cao et al. (2021) found that the spatial distribution of AK status increased first and then decreased from north to south in Shaanxi Province.

Soil N:P ratio and the influencing factors

Soil N:P ratio can be used as a diagnostic index of nitrogen saturation and also for determining current limiting nutrients (Wang et al., 2010). According to the USDA Soil Taxonomy System, the range of soil N:P* ratio for different soil types in China is 2.60–17.77. In this study, the soil N:P* ratio variation range of farmland soil in cities of Shaanxi Province was 1.72–4.85 (Fig. 7) and is lower than the average soil N:P ratio in China (Tian et al., 2010), which is consistent with the conclusions of many predecessors. For example, the average soil N:P ratio of cultivated land in Jiangxi Province was 3.38 (Jiang et al., 2017), the soil N:P ratio of converted farmland and tea planting land ranged from 1.42 to 2.37 (Zhu et al., 2016), and the variation range of soil N:P ratio in artificial grassland soil on the Loess Plateau ranged from 0.82 to 1.17, all well below the global average of different ecosystems soil N:P levels (Ou et al., 2019). We attributed this to the fact that Shaanxi Province is located in the Loess Plateau, and the parent material of loess is rich in phosphorus, which is an important reason for the lower soil N:P ratio than the national level.

In addition, the results of principal component analysis and correlation analysis showed that the differences in the soil N:P ratio among cities in Shaanxi Province were mainly explained by the soil parent material, topography, and the amount of soil fertilization. Soil N:P ratio was significantly positively correlated with soil TN, SOM, and AN contents and negatively correlated with soil pH, TP, longitude, latitude, and altitude (Fig. 8), which is similar to the results of some previous studies, such as soil N:P ratio decreased with increasing latitude in acacia forests on the Loess Plateau (Li et al., 2015; Zhang et al., 2013); soil N:P ratio was significantly positively correlated with TN and TP contents in artificial grasslands in the

hilly and ravine areas of the Loess Plateau (Ou et al., 2019); and soil N:P ratio in the grassland of the Qinghai-Tibet Plateau was negatively correlated with altitude (Zhang et al., 2008); soil N:P ratio in Hulunbuir grassland was significantly negatively correlated with longitude (Ding et al., 2012); global vegetation leaf N:P ratio increased significantly with decreasing latitude (Yang & Wang, 2011; Zhang et al., 2008). However, this is inconsistent with other research findings, such as leaf N:P ratio on the Loess Plateau increased with increasing latitude (Yang & Wang, 2011), leaf N:P ratio of terrestrial vegetation in China increased with the increase of latitude (Wang & Yu, 2008), and soil N:P ratio of grassland on the Qinghai-Tibet Plateau was positively correlated with latitude and longitude (Wang et al., 2010); the reason for this may be related to the unique geographical location of Shaanxi Province. The spatial pattern of soil N:P ratio variation is regulated by the hydrothermal conditions and changes in vegetation productivity along the altitude and latitude gradient. Moreover, the dominant factors regulating the spatial distribution pattern of soil stoichiometric characteristics are different at different scales (Feng & Bao, 2017), which may also be related to the plants and soil types formed by unique geographical and climatic conditions in Shaanxi Province.

Conclusions

In recent decades, large-scale evidence of spatio-temporal changes of soil N and P in Shaanxi Province has been provided for the first time in this study. It was observed that from the 1980s to 2017, with the large inputs of compound fertilizers, the soil TN, AN, and AP contents of farmland in Shaanxi Province increased, while the soil TP content decreased. Moreover, the soil N:P ratio in Shaanxi Province did not reach the national average. In the future, we recommend strict control of fertilizer application in central and southern Shaanxi and optimized fertilizer management in northern Shaanxi to improve ground strength and achieve increased yields.

Declarations

Ethics approval and consent to participate   All authors have read, have understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors and are aware that with minor exceptions; no changes can be made to authorship once the paper is submitted. Not applicable. No animal testing was performed during this study.

Consent for publication   All the authors have consented for the communication and subsequent publication of the manuscript.

Conflict of interest   The authors declare no competing interests.

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