Soil fertility evaluation and spatial distribution characteristics of grassland in Qilian mountain nature reserve

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Soil fertility evaluation and spatial distribution characteristics of grassland in Qilian mountain nature reserve-Tibetan Plateau

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Abstract: The study assessed the overall soil characteristics of Qilian mountain grassland and rated soil nutrient status with the China second national soil census grading standard. The Nemerow index method was used to evaluate the soil fertility of different grassland types, and GIS was used to analyse the soil nutrients spatial distribution, provide a data basis for the ecological protection and restoration of the grassland. The study indicated that the content of soil organic matter, total N, total K, total P and available K were graded at level 2 (high) or above with content of 4.99-131.52, 0.63-4.97, 15.36-21.72, 0.81-1.69 and 0.21-1.06 g kg^{-1} respectively for most regions. Soil available P was graded as level 4 with the contents of 6.79-24.27 mg kg^{-1},. While the soil bulk density, total porosity and pH were 0.77-1.32 g cm^{-3}, 35.36-58.83% and 7.63-8.54, respectively. The soil comprehensive fertility index was in a ranking order of Temperate steppe >Alpine meadow > Alpine steppe >Upland meadow >Alpine desert>Lowland meadow>Temperate Desert Steppe >Temperate Desert, and the areas with high, medium and low soil fertility accounted for 63.19%, 34.24% and 2.57%. of the total grassland area of Qilian mountain soil fertility for different grassland types had different main limiting factors. The grassland soil fertility of Qilian mountain was generally at the mid-upper level. Considering the main limiting factors of different type grasslands and spatial distribution, the typical grasslands and meadows may need to apply acidic phosphate fertilizers, and desert grasslands to apply compound fertilizers of nitrogen and phosphorus to improve soil comprehensive fertility to improve grassland productivity.

Keywords: grasslands; soil fertility; Qilian natural reserve; spatial distribution characteristics;

Soil fertility has a directly impact on the health of grasslands and is also influenced by grassland vegetation (Hao et al., 2020). Without human disturbance, the growth and distribution of grassland vegetation is strongly affected by soil fertility apart from climate (Wang et al., 2016; Harpole et al., 2007).Soil fertility not only affects the growth of grassland vegetation, but also affects the grassland ecosystem health (Ma et al., 2019). Therefore, good understanding and objective evaluation of soil fertility characteristic is of great significance to restoration and reconstruction of regional vegetation, and improvement of fragile grassland ecosystem (Su et al., 2019; Jin et al., 2018).

Grassland soil fertility plays a key role in supporting grassland ecosystem services (Clanet, 1980; Hu et al.,2018; Qu et al.,2015). Soil organic matter, nitrogen, phosphorus, potassium, soil density and pH are important components of soil fertility, while their content and spatial distribution directly affect grassland vegetation productivity (Wuest, 2015; Li et al., 2014). Many methods have been used for soil fertility evaluation, including Nemerow index method (Hua et al., 2018; Shahab et al., 2013), AHP (Keshavarzi et al., 2020; Sousa et al., 2012), correlation coefficient method, principal component analysis, etc. Among those evaluation methods, Nemerow index method has been well recognized due to it it can avoid the influence of subjective factors, which could highlight the influence of the worst factor of soil attribute factors on soil fertility (Bao et al., 2012).. Also Nemerow comprehensive index method reflects the law of the smallest factor of plant growth in ecology, which can improve the credibility of the evaluation results (An et al., 2015; Zhou et al., 2017).

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Comprehensive evaluation of soil fertility combining with geographic information system (GIS) has been widely used to assess spatial distribution characteristics of soil nutrients, which is helpful to explore the relationship between soil nutrients and environmental factors (Wang et al., 2007; Peng et al., 2013; Nie et al., 2016; Wang et al., 2009).

The Qilian mountain natural reserve is one of the most sensitive regions under global warming and an important ecological security barrier in northwestern of China (Wang et al., 2001). Grassland ecosystem is the largest ecological system in Qilian mountain natural reserve, which plays an important role in maintaining biodiversity, water conservation and ecological balance of the natural reserve (Li et al., 2019). In last few decades climate change, human activities and mismanagement have severely damaged the Qilian mountain grassland ecosystem..Understanding the current status of grassland soil in Qilian mountain is of great significance to the health and sustainable development of grassland ecosystems. There are many types of grasslands in Qilian mountain. Due to differences in terrain, rainfall and temperature, the distribution of the same type of grassland is very patchy and has discontinuities and irregularities. Previous studies found that different grassland types have large differences in soil nutrients due to the differences in vegetation types and utilization methods (Fayiah et al., 2019; Chen et al., 2020). Many studies have been carried out on the soil of degraded grassland in Qilian mountain (Cheng et al., 2019; Wang et al., 2018; Chen et al., 2016). However; there are few studies on grassland soil fertility and its spatial distribution characteristics in Qilian mountain. Therefore, the aims of this study were 1) to investigate the soil of different type grasslands in Qilian mountain natural reserve, 2) to analyze the distribution characteristics of soil fertility index, and 3) to determine the limiting factors for grassland soil fertility in Qilian mountain nature reserve, which can help to provide scientific insight for improving grassland ecological services.

1 Materials and methods

1.1 Study area

The study sites were located in the Qilian mountain nature reserve in Gansu province, China (94°10′-103°04′E, 35°50′-39°19′N). From southeast to northwest at horizontal direction, there are four vegetation zones in the order of forest, shrub, grassland and desert. At vertical direction, from low to high altitude, there are three vegetation belts: grassland belt, forest belt and alpine meadow grassland belt. The main types of soil are mountain gray cinnamon soil, subalpine meadow soil, alpine meadow soil and alpine cold desert soil. The annual precipitation varies from 100 to 500mm, mostly occurring during June to September. The average annual temperature is from -0.6 to 2.0°C; the average annual relative humidity is from 20% to 70%; the average annual evaporation is about 1200-1400 mm; and the frost-free period is about 90-120 days (http://www.qilianshan.com.cn).

1.2 Sites selection and Sample collection

This study sites were mainly located on the Qilian mountain natural reserve in Gansu province, China. The grassland types were Temperate steppe (TS), Alpine meadow (AM), Alpine steppe (AS), Upland meadow (UM), Alpine desert (AD), Temperate desert steppe (TDS), Lowland meadow (LM), Temperate desert (TD)(Table 1).

The sampling time of this study was from July to August 2019, when the plants were in full bloom. The central points of the typical distribution area of the above 8 types of grasslands (AM, TS, LM, AS, UM, TDS, AD and TD) were selected as the sampling sites. A 200-meter sample line was randomly set for each sample site and the sample spots were set for every 20-meter intervals. Four soil samples were taken at each sample spot using soil drill at a depth of 0-10 cm, 10-20 cm and 20-30 cm respectively. The four soil samples from each layer were mixed as one sample for that layer. The samples were put into a sample bag and taken back to a laboratory for air-drying for ~~further test~~. Three soil samples were taken from each layer at each sample site. Meanwhile, a 100 cm^3 soil clod was taken using ring knife method at each soil layer to measure soil bulk density and total porosity.

Table 1 Information of the sample sites

Type Grassland	Altitude m	longitude and latitude	Main plant species	Coverage %
Lowland meadow (LM)	1364	39°40′35.02″N 99°8′45.09″E	*Phragmites australis* (Cav.) Trin. ex Steud, *Achnatherum splendens, Sophora alopecuroides L.*	48.33
Upland meadow (UM)	3114	37°11′36.47″N 102°43′42.73″E	*Potentilla anserina L., Poa annua* L., *Elymus nutans* Griseb., *Melissilus ruthenicus*(L.) Peschkova, *Artemisia annua* L..	81.67
Alpine meadow (AM)	2977	37°10′48.66″N 102°47′13.83″E	*Polygonum viviparum* L., *Kobresia myosuroides* (Villars) Fiori, *Melissilus ruthenicus(L.) Peschkova, Artemisia annua Linn., Saussurea japonica* DC.	85.00
Temperate steppe (ST)	2817	37°22′13.68″N 102°40′44.93″E	*Poa annua L., Kobresia myosuroides* (Villars) Fiori, *Stipa capillata Linn., Potentilla anserina L. , Artemisia annua Linn.*	85.00
Alpine steppe (AT)	3735	39°16′32.99″N 97°42′52.57″E	*Stipa purpurea, Kobresia myosuroides (Villars) Fiori, Poa annua L., Potentilla anserina L., Androsace umbellate*	85.00
Temperate desert Steppe (TDS)	2139	38°57′57.23″N 99°47′41.95″E	*Sympegma regelii Bunge, Salsola collina Pall., Allium polyrhizum Turcz, Stipa capillata Linn., Ajania nematoloba*	43.75
Temperate Desert (TD)	1358	39°29′29.11″N 99°18′45.00″E	*Nitraria tangutorum Bobr, Nitraria sphaerocarpa Maxim, Suaeda glauca (Bunge) Bunge, Sympegma regelii Bunge*	31.67
Alpine desert (AD)	4290	39°15′34.39″N 97°45′6.70″E	*Rhodiola rosea L., Saussurea japonica DC., Kobresia myosuroides (Villars) Fiori*	28.33

1.3 Sample analyses

Soil bulk density was determined by the Core method (Dong et al., 2012). Total porosity was determined by Water immersion weighing method (Soil Physics institute, 1978). Soil samples were air-dried at room temperature, and visible roots and other debris in the soil were removed. Each soil sample was sieved through a 2-mm sieve. Soil organic matter was determined by the Walkley–Black method (Nelson and Sommers, 1996). Total N was determined by the Kjeldahl acid digestion method (Foss Kjeltec 8400, FOSS, DK) (Nelson and Sommers, 1996). Total P was measured by Mo-Sb colorimetry (UV-2102C, UNICO, Shanghai, China) (Nelson and Sommers, 1996). Total K was measured by Sodium hydroxide melting- Flame photometer method (Nelson and Sommers, 1996). Available P was determined by the Mo-Sb-Ascorbic acid colorimetric method after acid digestion (Nelson and Sommers, 1996). Available K was determined by Ammonium acetate-Flame photometer method (Nelson and Sommers, 1996).

1.4 Evaluation of soil fertility

1.4.1 Evaluation of individual indicators of soil fertility

This study used the China second soil census standard (Table 1) to rank the grassland soil organic matter, total N, total P, total K, available P, available N, pH, bulk density and total porosity indicators of Qilian mountain grassland, and to compare the differences between different grassland types (Zhou et al., 2017).

Table 2. Classification criteria used for soil nutrients

Grades	SOC g kg^{-1}	Total N g kg^{-1}	Total P g kg^{-1}	Total K g kg^{-1}	Available P mg kg^{-1}	Available K mg kg^{-1}	Comment
1	＞40	＞2.0	＞1.0	＞25	＞40	＞200	Very high
2	30-40	1.5-2.0	0.8-1.0	20-25	20-40	150-200	High
3	20-30	1.0-1.5	0.6-0.8	15-20	10-20	100-150	Upper
4	10-20	0.75-1.0	0.4-0.6	10-15	5-10	50-100	Mid-low
5	6-10	0.5-0.75	0.2-0.4	5-10	3-5	30-50	Low
6	＜6	＜0.5	＜0.2	＜5	＜3	＜30	Very low

1.4.2 Comprehensive soil fertility evaluation

The improved Nemerow index method was used to comprehensively evaluate the soil fertility quality of Qilian mountain (Zhou et al., 2017; Zhou et al., 2018). According to the grading standards of soil properties in the China second soil census standard (Table 2), the selected index parameters were standardized to eliminate the dimensional difference between the parameters. The standardized treatment methods are as follows:

When the attribute value belongs to the level ~~of~~ low, $c_i \le x_a$, $F_i = c_i / x_a$ $(F_i \le 1)$ (1)

When the attribute value belongs to the level ~~of~~ upper, $x_a < c_i \le x_c$, $F_i = 1+(c_i - x_a)/(x_c - x_a)$ $(1 < F_i \le 2)$ (2)

When the attribute value belongs to the level ~~of~~ high, $xc < ci \le xp$, $Fi = 2+(ci-xc)/(xp-xc)$ $(2 < Fi \le 3)$ (3)

When the attribute value belongs to the level ~~of~~ very high, $ci > x$, $Fi=3$ (4)

In the above formulas, F_i is the attribute division coefficient, c_i is the measured value of the attribute, and x_a, x_c, and x_p are the classification indexes.

The improved Nemerow index method was then used to comprehensively evaluate the grassland soil fertility in Qilian mountain. The revised Nemerow formula is as follows:

$$F=\sqrt{\frac{Fi^2+Fimin^2}{2}}\cdot\left(\frac{n-1}{n}\right)$$

Where F is the soil comprehensive fertility index, F_i is the average value of each sub-fertility index, F_{imin} is the minimum value of each sub-fertility index, and n is the number of participating indicators.

Table 3 Grading criterion for various soil properties in the Nemerow grading method

Soil properties		Soil bulk density	total porosity	pH	SOM	Total N	Total P	Total K	Available P	Available K
Classification	x_p	0.95	0.50	7	30	2.00	1.0	25	20	200
index of	x_c	1.10	0.40	8	20	1.50	0.6	15	10	100
Nemorow	x_a	1.25	0.30	9	10	0.75	0.4	5	5	50

1.5 Soil comprehensive fertility index spatial distribution

Analysis method based on multiple regression and residues (AMMRR) ~~had~~ been widely used in many studies for grassland spatial interpolation (Liu et al., 2012; Guo et al., 2011). This method is more accurate than many other interpolating methods and can also effectively avoid~~s~~ systematic errors. In this paper, based on the comprehensive fertility index determined by the improved Nemerow index method, and the ArcGIS10.2.2

(Provide a reference here) was used to conduct the spatial analyses including extracting the center points of different grassland types (Figure 1), assigning values for grassland types, performing AMMRR interpolation, and drawing the Qilian mountain grassland soil fertility index spatial distribution. The comprehensive fertility index was divided into low (<1.50), medium (1.50-2.00), and high (> 2.00).

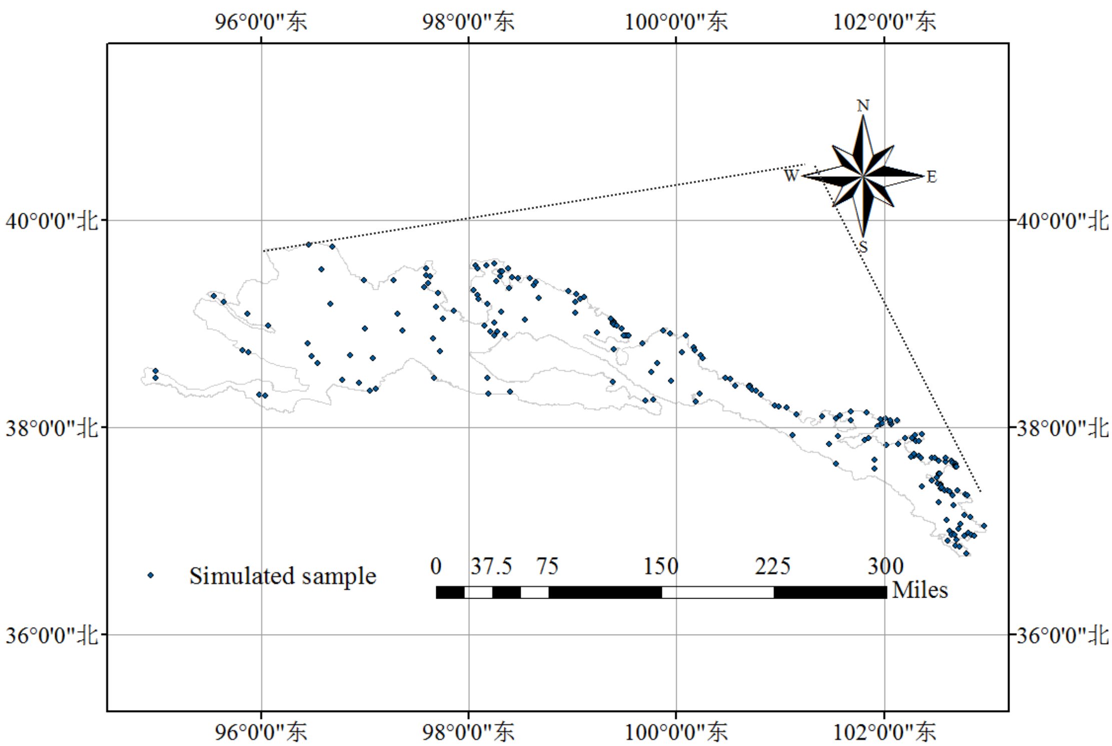

Fig.1 based on ArcGIS10.2.2 extract the center points of different grassland types patches spatial distribution

1.6 Statistical analyses

Statistical analyses were conducted using SPSS (version 19.0 SPSS Inc., Chicago, IL, USA). All results were presented as mean and standard deviations. One-way ANOVA and least significant difference (LSD) tests were declared at P＜0.05.

2 Results

2.1 Characteristics of grassland soil fertility indexes

The soil bulk density of Qilian mountain grassland was 0.77-1.32 g cm^{-3}, with an average value of 1.01 g cm^{-3} and a CV of 17.88% (Table 4). The total porosity was 35.36-58.83%, with an average value of 48.25% and a CV of 16.38%. The pH was 7.63-8.54, with an average value of 8.07 and a CV of 4.71%. The total N was 0.63-4.97 g kg^{-1}, with an average value of 2.38 g kg^{-1} and a CV of 75.49%. The total P was 0.81-1.69 g kg^{-1}, with an average value of 1.18 g kg^{-1} and a CV of 26.67%. The total K was 15.36-21.72 g kg^{-1}, with an average value of 19.92 g kg^{-1} and a CV of 9.88%. The available P was 6.79-24.27 mg kg^{-1}, with an average value of 12.81 mg kg^{-1} and a CV of 43.09%. The available K was 0.21-1.06 g kg^{-1}, with an average value of 0.40 g kg^{-1} and a CV of 68.00%. The soil organic matter was 4.99-131.52 g kg^{-1}, with an average value of 51.23 g kg^{-1} and a CV of 95.32%.

Table 4. Descriptive statistics of grassland soils in Qilian mountain nature reserve

Item	MIN	MAX	Mean	SD	CV%
Soil bulk density g cm^{-3}	0.77	1.32	1.01	0.18	17.88
Total porosity %	35.36	58.83	48.25	7.90	16.38
pH	7.63	8.54	8.07	0.38	4.71
Total N g kg^{-1}	0.63	4.97	2.38	1.8	75.49
Total P g kg^{-1}	0.81	1.69	1.18	0.31	26.67
Total K g kg^{-1}	15.36	21.72	19.92	1.965	9.88
Available P mg kg^{-1}	6.79	24.27	12.81	5.52	43.09
Available K g kg^{-1}	0.21	1.06	0.40	0.27	68.00
Soil organic matter g kg^{-1}	4.99	131.52	51.23	48.83	95.32

2.2 Soil physical and chemical features in different type grasslands

The soil fertility index for different type grasslands ~~were~~ shown in Table 5. Except for total K, there were significant difference ($P < 0.05$) between all other soil fertility indexes of different grassland types . Soil bulk density was in a ranking order of desert type > meadow type > steppe type, or AM > TS > LM > AS > UM > TDS > AD > TD. The total porosity was in a ranking order of TS > AS > AM > UM > TDS > LM > AD > TD.The pH was in a ranking order of TD > LM > TDS > UM > AD > AS> AM > TS. Total N was in a ranking order of AM > TS > AS > UM > AD > TDS > LM > TD. Thesoil organic matter was in ranking order of TS > AM > AS > UM > AD > TDS > LM > TD. Thet total P was in a ranking order of AM > UM > LM > TS > AS > TD > AD > TDS. The available P was in a ranking order of LM > TS > AM > AS > UM > TD > TDS > AD. The available K was in a ranking of LM > UM > AS > TD >TS > AM > AD > TDS.

Table 5 Soil physical and chemical properties in different Grassland types in Qilian mountain Nature Reserve

Grassland Type	Soil bulk density g cm^{-3}	Total porosity %	pH	Total N g kg^{-1}	Total P g kg^{-1}	Total K g kg^{-1}	Available P mg kg^{-1}	Available K g kg^{-1}	SOM g kg^{-1}
LM	1.05± 0.09bc	43.65±4.83cd	8.51±0.04a	0.64±0.10d	1.36±0.09bc	19.47±2.66a	24.27±3.55a	1.06±0.91a	12.67±1.63cd
UM	0.95±0.07cd	48.73±2.06bc	7.97±0.24b	2.01±0.51c	1.53±0.23ab	15.36±1.34a	12.34±2.97b	0.45±0.06b	36.87±16.45c
AM	0.83± 0.09de	51.59±5.45b	7.76±0.26d	4.81±0.13a	1.69±0.16a	21.72±0.99a	13.73±7.54ab	0.30±0.15bc	116.46±28.35a
TS	0.77± 0.03df	54.98±1.92ab	7.63±0.10e	4.97±0.78a	1.21±0.08cd	21.18±1.02a	14.94±5.69ab	0.30±0.06c	131.52±14.33a
AS	0.91± 0.05d	58.83±2.50a	7.83±0.03bc	3.36±0.35b	0.99±0.26de	20.60±0.87a	13.65±6.95ab	0.35±0.08bc	65.56±20.49b
TDS	1.14± 0.09b	52.53±1.06b	8.50±0.03a	0.77±0.12d	0.81±0.16e	20.37±2.43a	7.96±0.65b	0.21±0.03c	13.18±1.94cd
TD	1.32± 0.06 a	35.36±4.69e	8.54±0.05a	0.63±0.08d	0.98±0.06de	20.76±0.69a	8.81±2.22b	0.32±0.05bc	4.99±0.99d
AD	1.11± 0.06b	40.32±2.18de	7.84±0.04bc	1.88±0.07c	0.90±0.06e	19.99±1.47a	6.79±0.97b	0.24±0.04c	28.65±1.90cd

Note: Data are presented as the mean±SD; Different small letters in the same row mean significant difference at 0.05 level. TS, Temperate steppe; AM, Alpine meadow; AS, Alpine steppe; UM, Upland meadow; AD, Alpine desert; TDS, Temperate Desert Steppe; LM, Lowland meadow; TD, Temperate Desert.

2.3 Soil physical and chemical spatial distribution

The soil physical and chemical spatial distributions were showed in Fig.2. Soil bulk density in most areas was 0.75-0.94 g cm^{-3}. Total porosity in most areas was 50-60%. pH in most areas was 8-9. The SOM in most areas was 30-134 g kg^{-1}. The total N in most areas was 2.0-5.0 g kg^{-1}. The total P in most areas was 1.0-1.75 g kg^{-1}. The total K in most areas was 15-25 g kg^{-1}. The Available P in most areas was 10-20 mg kg^{-1}. The Available K in most areas was 0.3-1.5 g kg^{-1}.

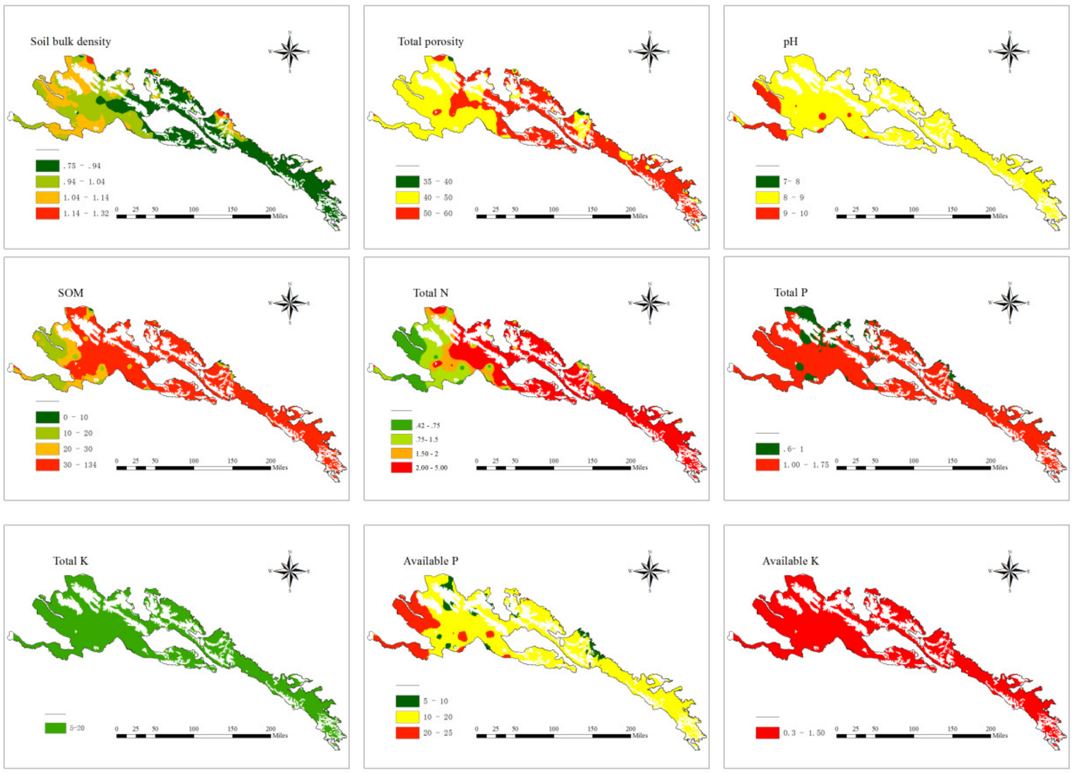

Fig.2 Spatial distributions of soil physical and chemical characteristics.

2.4 Soil comprehensive fertility index

The soil comprehensive fertility index of different type grasslands ranged from 1.14 to 2.32 (Table 6). The soil comprehensive fertility index was significantly higher in AM, UM, AS and TS than in AD, significantly higher in AD than in LM and TDS, and significantly higher in TDS than in TD, but no significant differences were found among others. The soil comprehensive fertility index was in a ranking order of TS > AM > AS > UM > AD >LM > TDS > TD.

The soil fertility of Qilian mountain grassland was at a moderate or high level (Fig.3). In terms of spatial distribution, the soil comprehensive fertility index was higher in eastern and western of Qilian mountain, and the soil fertility in the central region was moderate. There are only a few areas where the soil fertility of the grassland was low, distributed in the marginal regions of the western and central regions. The areas with high, medium and low soil fertility accounted for 63.19%, 34.24% and 2.57% of the total grassland area of Qilian mountain.

Table 6 Comprehensive evaluation of different Grassland Types in Qilian mountain Nature Reserve soil fertility using Nemerow index

Grassland Type	F_i										
	Soil bulk density	Total porosity	pH	Total N	Total P	Total K	Available P	Available K	SOM	$\overline{Fi}$	F
LM	2.67	2.37	1.49	0.85	3.00	2.45	3.00	3.00	1.27	2.23	1.50c
UM	3.00	2.87	2.03	3.00	3.00	2.34	2.23	3.00	3.00	2.69	2.12a
AM	3.00	3.00	2.24	3.00	3.00	2.67	2.37	3.00	3.00	2.81	2.26a
TS	3.00	3.00	2.37	3.00	3.00	2.62	2.49	3.00	3.00	2.83	2.32a
AS	3.00	3.00	2.17	3.00	2.98	2.56	2.37	3.00	3.00	2.79	2.22a
TDS	1.73	3.00	1.50	1.03	2.53	2.53	1.59	3.00	1.32	2.02	1.43c
TD	1.06	2.54	1.46	0.84	2.95	2.58	1.76	3.00	0.50	1.74	1.14d
AD	1.93	2.03	2.16	2.76	2.75	2.50	1.36	3.00	2.87	2.37	1.72b

Note: TS, Temperate steppe; AM, Alpine meadow; AS, Alpine steppe; UM, Upland meadow; AD, Alpine desert; TDS, Temperate Desert Steppe; LM, Lowland meadow; TD, Temperate Desert.

2.5 limiting factors for grassland soil comprehensive fertility

The different type grasslands soil fertility had different major limiting factors (Table 6For example, the pH, total N and SOM were the main factors limiting soil fertility in LM, and pH and available P were the main factors limiting soil fertility in UM, AM, TS and AS. The Soil bulk density, pH, total N, SOM and available P were the main factors limiting soil fertility in TD and TDS. Soil bulk density and available P were the main factors limiting soil fertility in AD. The limiting factors for grassland soil comprehensive fertility of Qilian mountain grassland ~~was~~ showed in Fig.3.

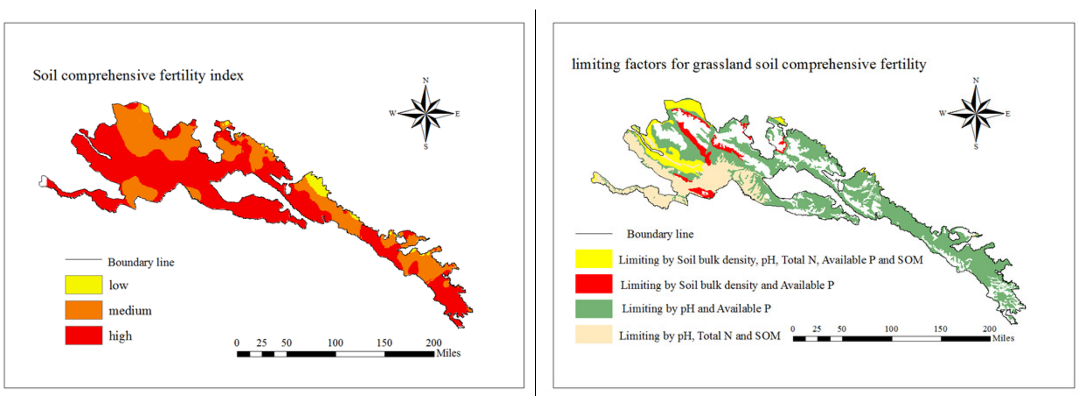

Fig.3 Spatial distribution of grassland soil comprehensive fertility index and limiting factors for grassland soil comprehensive fertility.

3 Discuss

Soil organic matter is closely related to soil fertility and soil health. Nitrogen, phosphorus and potassium provide essential nutrients for plant growth and development, and are the main components of soil nutrients (Zhang et al.,2013; Zhou et al., 2016). The content of soil organic matter, total N, total P and available K were graded as level 2 (high) or above for Qilian mountain grasslands according to the classification of China second soil census standards, with content of soil organic matter, total N, total P and available K of 4.99-131.52, 0.63-4.97, 0.81-1.69 and 0.21-1.06 g kg^{-1} for most regions. Available P was graded as level 4 with the contents of 6.79-24.27 mg kg^{-1}. Ours study found that the difference between the maximum value and the minimum value of each fertility index was quite large, which means there was a background difference in the distribution of soil nutrients This finding was similar to the results obtained by Cui et al. (2010) and Zhou et al. (2017) for urban green space. Soil density suitable for plant growth is generally within 1.14 to 1.26 g cm^{-3} (Reisinger et al., 1988). The average soil bulk density of grassland in Qilian mountain was 1.01 g cm^{-3}, with most of the area between 0.75-1.14 g cm^{-3}. The grassland soil comprehensive fertility index of Qilian mountain decreases from east to west. The spatial distribution and succession of grassland types were the main factors affecting grassland soil fertility. From west to east, there are desert, typical grassland and meadow grassland types in Qilian mountain mainly. CV is an indicator of degree of dispersion of the sample. CV <10% means weak variation, 10-100% means medium variation and > 100% means strong variation. The results of ours study indicated that, except for soil pH and total K, which were weak variations, the other nutrient indicators were all moderately variable.

Grassland type is influenced by climate, vegetation and soil (Hu et al., 1978). Soil as the substrate of grassland, its physical and chemical properties of different types of grasslands provide important insight to understand grassland degradation and evolution (Gou et al., 2019; Li et al., 2019). Zhang et al (2019) found that the contents of total N, organic carbon and soluble organic carbon of different alpine types of grassland were in an order of alpine meadow> alpine meadow grassland> alpine grassland> alpine desert, and the differences between alpine types of grasslands were significant. This study observed that the ranking of the different types of grassland was desert type > meadow type > steppe type for soil bulk density, which suggested the changes of total porosity were opposite to soil bulk density. Furthermore, the total N, soil organic matter and soil comprehensive fertility index in different grassland types had significant differences. Since soil nutrients were mainly derived from the decomposition of animals, plants, microbial residues, litters, root exudates and soil parent materials, spatial heterogeneity of soil fertility distribution in different types of grassland observed in this study indicated these grasslands were influenced through the different climate and vegetation (Wei et al., 2018). Soil organic matter and nitrogen mainly came from the decomposition of organic matter, but moisture and temperature were the dominant factors controlling the decomposition rate of organic matter. This was why Ren and Hu (2008) used rainfall and temperature accumulated as a first-class classification index to classify grassland types in CSCS.

The rational construction of comprehensive evaluation factors was the key content of comprehensive evaluation of soil fertility, which directly determined the rationality and objectivity of evaluation results (Chen et al., 2019; Science - Soil Science, 2019). In many studies, the evaluation indicators of soil fertility mainly focused on nutrients such as soil organic matter, nitrogen, phosphorus and potassium (Chen et al., 2019; Science-Soil Science, 2019; Yu et al., 2018). In our study, the evaluation indexes of soil fertility incorporated the soil bulk density and total porosity, which could reflect the status of soil fertility from different angel as soil compactness, permeability, infiltration performance and water holding capacity were also reflected by soil bulk density and total porosity (Garrigues et al., 2012). The modified Nemero formula highlights the effect of the minimum factor on soil fertility, reflecting the law of the smallest factor of plant growth in ecology (An et al., 2015), and the soil minimum factor can be judged according to the minimum value of the Fi in the Nemero formula. In ours study, the different type grasslands soil fertility had different main limiting factors. Such as pH, total N and SOM were the main factors limiting soil fertility in LM, and pH and available P was the main factors limiting soil fertility in UM, AM, TS and AS. The Soil bulk density, pH, total N, SOM and available P were the main factors limiting soil fertility in TD and TDS. Soil bulk density and available P were the main factors limiting soil fertility in AD. The Nemero index method can objectively reflect the comprehensive fertility characteristics of grassland soil, but many studies have not analyzed the spatial distribution characteristics of soil fertility in depth (Bao et al., 2012; Fan, et al., 2012). Ours research combined GIS and soil science to draw a spatial distribution map of grassland soil fertility in Qilian mountain, which more intuitively reflected the distribution of grassland soil fertility. In ours study, the areas with high, medium and low soil fertility accounted for the total grassland area of Qilian mountain was 63.19%, 34.24% and 2.57%.

Grassland was an important foundation for the construction of the Qilian mountain ecosystem. Based on the research results, the actual distribution of grassland types, Reasonable management could promoted benign and sustainable development of grassland ecosystems

4 Conclusions

The results of soil nutrients and their spatial distribution of grasslands in Qilian mountain showed that, except for the low-available P content, other nutrient indicators had reached level 2 and above in China's second soil census standard, while soil bulk density was relative low and pH was relatively high. The soil comprehensive fertility index was in a ranking order of TS > AM > AS > UM > AD >LM > TDS > TD, and the areas with high, medium and low soil fertility accounted for 63.19%, 34.24% and 2.57% of the total grassland area of Qilian mountain. The different type grasslands soil fertility had different main limiting factors. The grassland soil fertility of Qilian mountain was generally at the mid-upper level. The appropriate management methods should be adopted to improve soil fertility combining with the main limiting factors, to improve grassland ecological service function.

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Table 1(on next page)

nformation of the sample sites, Classification criterion of soil nutrients, Grading criterion for various soil properties in the Nemerow grading method, Criteria for determining the organic matter, total nitrogen and bulk density of grassland soi

nformation of the sample sites, Classification criterion of soil nutrients,Grading criterion for various soil properties in the Nemerow grading method, Criteria for determining the organic matter, total nitrogen and bulk density of grassland soils with different degradation degrees,Descriptive statistics in various studied parameters of grassland soil in Qilian Mountain Nature Reserve

Table1. information of the sample sites

Type grassland	Altitude m	longitude and latitude	Main plant species	Coverage %
Lowland meadow (LM)	1364	39°40′35.02″N 99°8′45.09″E	*Phragmites australis* (Cav.) Trin. ex Steud, *Achnatherum splendens, Sophora alopecuroides L.*	48.33
Upland meadow (UM)	3114	37°11′36.47″N 102°43′42.73″E	*Potentilla anserina L., Poa annua* L., *Elymus nutans Griseb., Melissilus ruthenicus*(L.) Peschkova, *Artemisia annua* L..	81.67
Alpine meadow (AM)	2977	37°10′48.66″N 102°47′13.83″E	*Polygonum viviparum* L., *Kobresia myosuroides* (Villars) Fiori, *Melissilus ruthenicus(L.) Peschkova, Artemisia annua Linn., Saussurea japonica* DC.	85.00
Temperate steppe (ST)	2817	37°22′13.68″N 102°40′44.93″E	*Poa annua L., Kobresia myosuroides* (Villars) Fiori, *Stipa capillata Linn., Potentilla anserina L. , Artemisia annua Linn.*	85.00
Alpine steppe (AT)	3735	39°16′32.99″N 97°42′52.57″E	*Stipa purpurea, Kobresia myosuroides (Villars) Fiori, Poa annua L., Potentilla anserina L., Androsace umbellate*	85.00
Temperate Desert Steppe (TDS)	2139	38°57′57.23″N 99°47′41.95″E	*Sympegma regelii Bunge, Salsola collina Pall., Allium polyrhizum Turcz, Stipa capillata Linn., Ajania nematoloba*	43.75
Temperate Desert (TD)	1358	39°29′29.11″N 99°18′45.00″E	*Nitraria tangutorum Bobr, Nitraria sphaerocarpa Maxim, Suaeda glauca (Bunge) Bunge, Sympegma regelii Bunge*	31.67
Alpine desert (AD)	4290	39°15′34.39″N 97°45′6.70″E	*Rhodiola rosea L., Saussurea japonica DC., Kobresia myosuroides (Villars) Fiori*	28.33

Table2 Classification criterion of soil nutrients

Grades	SOC g kg^{-1}	Total N g kg^{-1}	Total P g kg^{-1}	Total K g kg^{-1}	Available P mg kg^{-1}	Available K mg kg^{-1}	Comment
1	＞40	＞2.0	＞1.0	＞25	＞40	＞200	Very high
2	30-40	1.5-2.0	0.8-1.0	20-25	20-40	150-200	High
3	20-30	1.0-1.5	0.6-0.8	15-20	10-20	100-150	Upper
4	10-20	0.75-1.0	0.4-0.6	10-15	5-10	50-100	Mid-low
5	6-10	0.5-0.75	0.2-0.4	5-10	3-5	30-50	Low
6	＜6	＜0.5	＜0.2	＜5	＜3	＜30	Very low

Table 3 Grading criterion for various soil properties in the Nemerow grading method

Soil properties		Soil bulk density	total porosity	pH	SOM	Total N	Total P	Total K	Available P	Available K
Classification	x_p	1.14	0.50	7	30	2.00	1.0	25	20	200
index of	x_c	1.04	0.40	8	20	1.50	0.6	20	10	100
Nemorow	x_a	0.94	0.30	9	10	0.75	0.4	5	5	50

Table4 Descriptive statistics in various studied parameters of grassland soil in Qilian Mountain Nature Reserve

Item	MIN	MAX	Mean	SD	CV%
Soil bulk density g cm^{-3}	0.77	1.32	1.01	0.18	17.88
Total porosity %	35.36	58.83	48.25	7.90	16.38
pH	7.63	8.54	8.07	0.38	4.71
Total N g kg^{-1}	0.63	4.97	2.38	1.8	75.49

Total P g kg^{-1}	0.81	1.69	1.18	0.31	26.67
Total K g kg^{-1}	10.24	14.48	13.28	1.31	9.88
Available P mg kg^{-1}	6.79	24.27	12.81	5.52	43.09
Available K g kg^{-1}	0.21	1.06	0.40	0.27	68.00
Soil organic matter g kg^{-1}	4.99	131.52	51.23	48.83	95.32

Table5 Soil physical and chemical properties in different Grassland Types in Qilian Mountain Nature Reserve

Grassland Type	Soil bulk density $g\ cm^{-3}$	Total porosity %	pH	Total N $g\ kg^{-1}$	Total P $g\ kg^{-1}$	Total K $g\ kg^{-1}$	Available P $mg\ kg^{-1}$	Available K $g\ kg^{-1}$	SOM $g\ kg^{-1}$
LM	1.05± 0.09bc	43.65±4.83cd	8.51±0.04a	0.64±0.10d	1.36±0.09bc	12.98±1.77a	24.27±3.55a	1.06±0.91a	12.67±1.63cd
UM	0.95±0.07cd	48.73±2.06bc	7.97±0.24b	2.01±0.51c	1.53±0.23ab	10.24±0.89a	12.34±2.97b	0.45±0.06b	36.87±16.45c
AM	0.83± 0.09de	51.59±5.45b	7.76±0.26d	4.81±0.13a	1.69±0.16a	14.48±0.66a	13.73±7.54ab	0.30±0.15bc	116.46±28.35a
TS	0.77± 0.03df	54.98±1.92ab	7.63±0.10e	4.97±0.78a	1.21±0.08cd	14.12±0.68a	14.94±5.69ab	0.30±0.06c	131.52±14.33a
AS	0.91± 0.05d	58.83±2.50a	7.83±0.03bc	3.36±0.35b	0.99±0.26de	13.73±0.58a	13.65±6.95ab	0.35±0.08bc	65.56±20.49b
TDS	1.14± 0.09b	52.53±1.06b	8.50±0.03a	0.77±0.12d	0.81±0.16e	13.51±1.62a	7.96±0.65b	0.21±0.03c	13.18±1.94cd
TD	1.32± 0.06 a	35.36±4.69e	8.54±0.05a	0.63±0.08d	0.98±0.06de	13.84±0.46a	8.81±2.22b	0.32±0.05bc	4.99±0.99d
AD	1.11± 0.06b	40.32±2.18de	7.84±0.04bc	1.88±0.07c	0.90±0.06e	13.33±0.98a	6.79±0.97b	0.24±0.04c	28.65±1.90cd

Note: Data are presented as the mean±SD; Different small letters in the same row mean significant difference at 0.05 level. TS, Temperate steppe; AM, Alpine meadow; AS, Alpine steppe; UM, Upland meadow; AD, Alpine desert; TDS, Temperate Desert Steppe; LM, Lowland meadow; TD, Temperate Desert.

Table 6 Comprehensive evaluation of different Grassland Types in Qilian Mountain Nature Reserve soil fertility via Nemerow index

Note: TS, Temperate steppe; AM, Alpine meadow; AS, Alpine steppe; UM, Upland meadow; AD, Alpine desert; TDS, Temperate Desert Steppe; LM, Lowland meadow; TD, Temperate Desert.

Figure 1

Fig.1 based on ArcGIS10.2.2 extract the center points of different grassland type patches spatial distribution

Fig.1 based on ArcGIS10.2.2 extract the center points of different grassland type patches spatial distribution

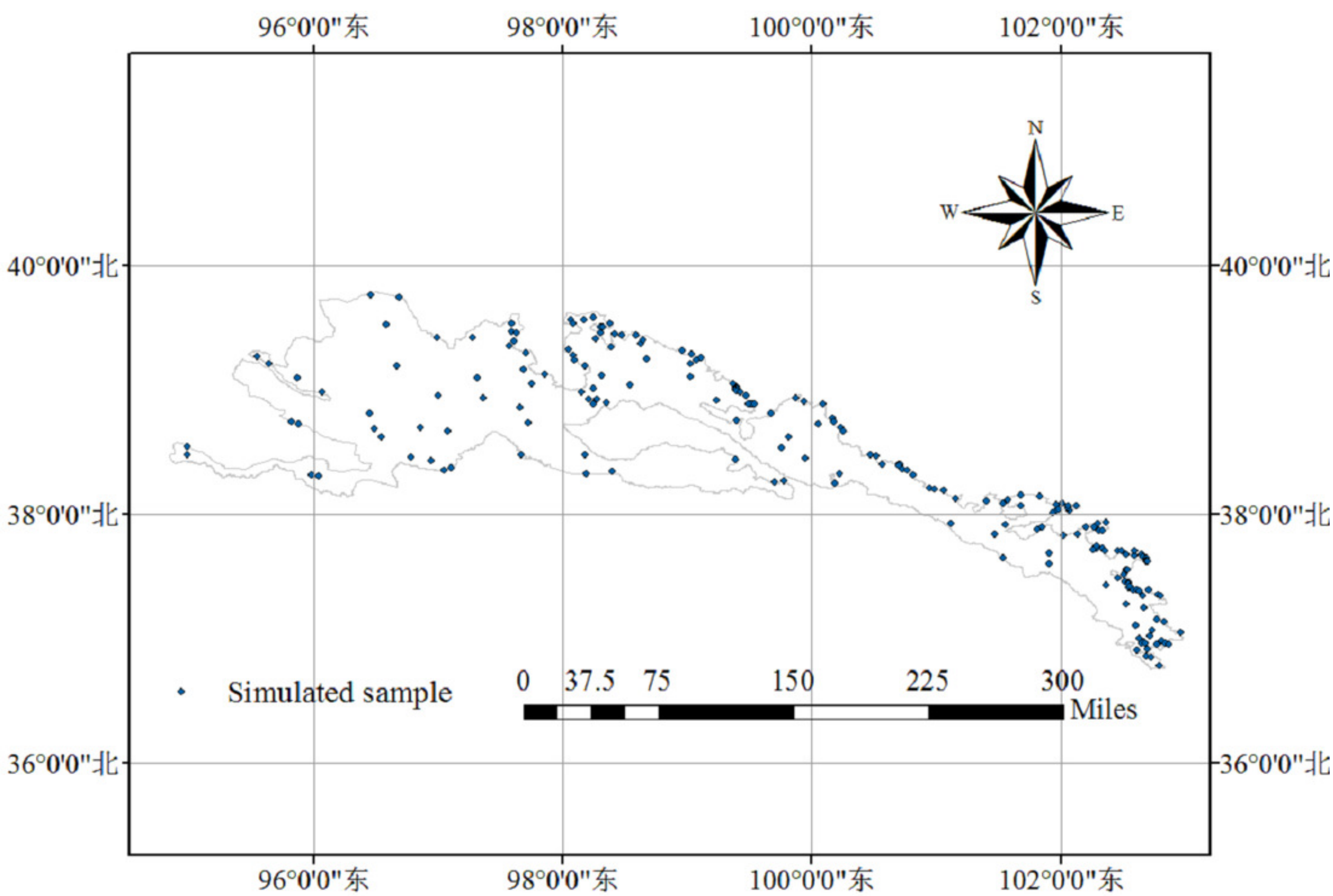

Figure 2

Fig.2 Soil physical and chemical spatial distribution

Fig.2 Soil physical and chemical spatial distribution

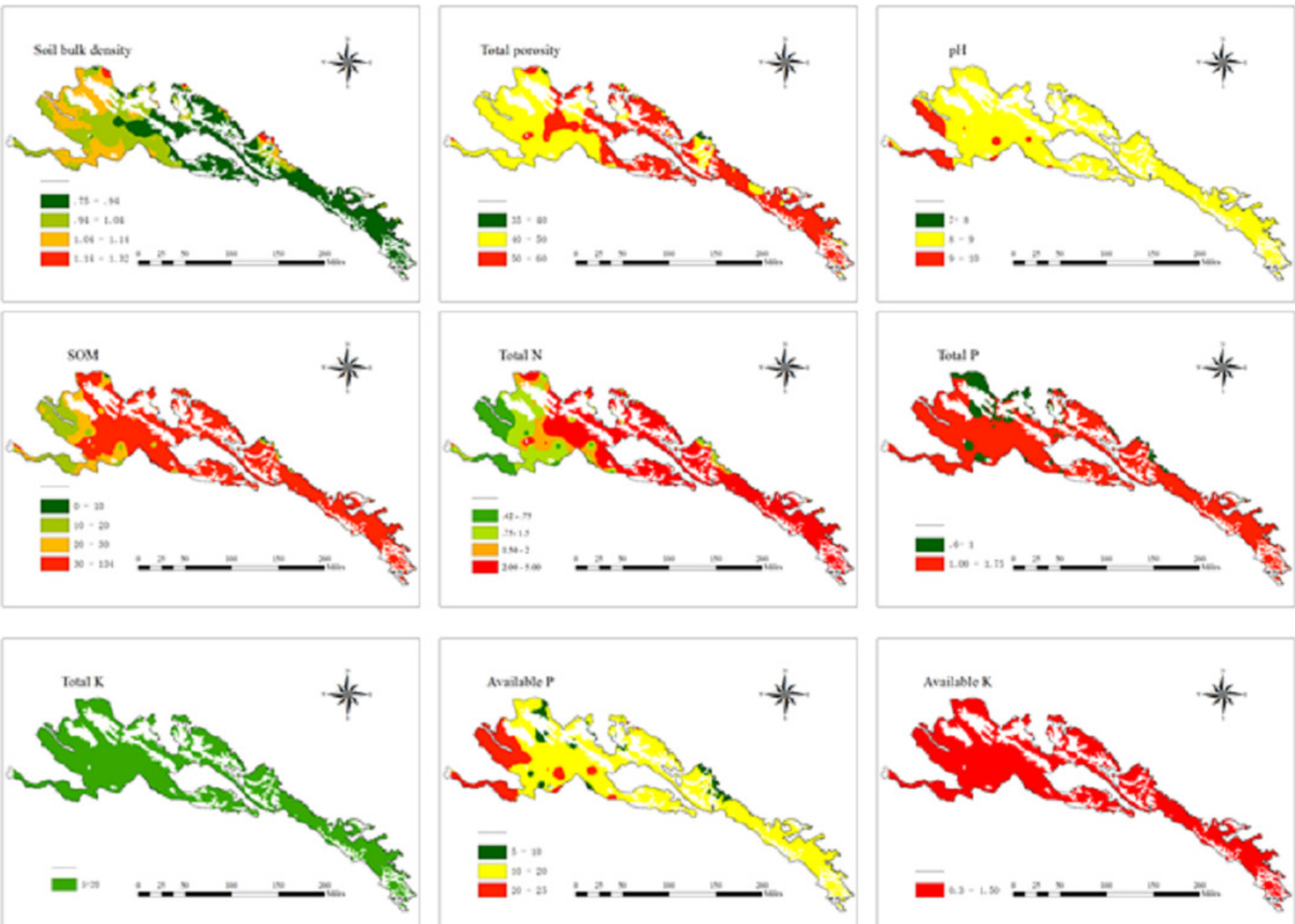

Fig.2 Soil physical and chemical spatial distribution