Soil Fertility Assessment of Urban Forest Green Spaces in Changchun (Postprint)

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Abstract

Taking Changchun urban forest green spaces as the research object, nine soil indicators were measured and the overall characteristics of soils in Changchun urban forest green spaces were evaluated according to the classification standards of the National Second Soil Census. The Nemerow index method was employed to analyze soil fertility across different forest types, administrative districts, and ring roads in Changchun urban forest green spaces, and ArcGIS was utilized to analyze the spatial distribution characteristics of soil nutrients, aiming to provide a basis and recommendations for Changchun urban forest construction. Compared with the classification levels established by the National Second Soil Census (six levels), the average soil organic matter content (34.51 g/kg) and its spatial distribution (most areas >30 g/kg) reached Level 2, indicating a high content level; total nitrogen (mean 1.37 g/kg), alkali-hydrolyzable nitrogen (mean 133.04 mg/kg), available phosphorus (mean 38.47 mg/kg), and their spatial distributions all achieved Level 3 or above; total potassium (mean 58.7 g/kg) and available potassium (mean 255.85 mg/kg), along with their spatial distributions, reached Level 1, indicating a very high content level; the average total phosphorus content was 0.51 g/kg, with most areas spatially concentrated at 0.4-0.6 g/kg, corresponding to Level 4, a medium-low content level. Soil pH ranged from 5.43-8.89, and bulk density ranged from 1.11-1.62 g/cm³. Nemerow comprehensive fertility index analysis showed that most areas in Changchun city were between 1.5-1.8, at a medium level (ranking third in the four-level system). Differences among forest types were mainly manifested in pH, total nitrogen, total phosphorus, and alkali-hydrolyzable nitrogen ($P < 0.05$); differences among ring roads were primarily in pH, organic matter, and total phosphorus ($P < 0.05$); while differences among administrative districts involved the most indicators, including organic matter, total nitrogen, alkali-hydrolyzable nitrogen, total phosphorus, available phosphorus, and pH ($P < 0.05$). The comprehensive fertility index showed: landscape forest > unit-affiliated forest = farmland shelter forest > roadside forest, Lvyuan District > Chaoyang District > Nanguan District > Erdao District > Kuancheng District, 1st Ring > 3rd = 4th Ring > 2nd Ring > outside 4th Ring. Based on these results, measures such as soil loosening, composting of litter, increasing application of nitrogen-phosphorus organic fertilizer while controlling potassium fertilizer, and planting nitrogen-fixing and low-phosphorus-tolerant plants can be adopted to promote Changchun urban forest construction and enhance the ecological service functions of urban vegetation.

Full Text

Preamble

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Soil Fertility Evaluation for Urban Forests and Green Spaces in Changchun City

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Abstract

Urban soil fertility is a critical factor for urban forestry and greening. However, no comprehensive city-scale soil fertility evaluation has been conducted to guide greening practices in Changchun City. This study collected 197 soil samples from the 0–20 cm layer to determine soil organic matter (SOM), total nitrogen (TN), total phosphorus (TP), total potassium (TK), available nitrogen (AN), available phosphorus (AP), available potassium (AK), pH, and soil bulk density. Variables were analyzed across different forest types (roadside forest [RF], affiliated forest [AF], landscape forest [LF], and farmland shelterbelt forest [FF]), administrative districts (Chaoyang, Lvyuan, Nanguan, Kuancheng, and Erdao districts), and ring road gradients (1st–4th ring roads and outside the 4th ring). Classification criteria from the 2nd National Soil Survey (6-grade evaluation) and a modified Nemorow index were used to assess soil fertility. Kriging interpolation in ArcGIS software was employed to map the spatial distribution of soil nutrients and fertility.

Reference to the 6-grade criteria from the 2nd National Soil Survey indicated

that SOM in Changchun was classified as Grade 2 (high level), averaging 34.51 g/kg, with most regions exceeding 30 g/kg. TN, AN, and AP were classified as Grade 3 or higher, averaging 1.37 g/kg, 133.04 mg/kg, and 38.47 mg/kg, respectively. Spatial mapping revealed that most urban areas had TN concentrations of 1-1.5 g/kg, AN of 90–150 mg/kg, and AP of 20–40 mg/kg. TK and AK were classified as the highest grade (Grade 1), averaging 58.7 g/kg and 255.85 mg/kg, respectively, with most regions showing 50–60 g/kg and 200–300 mg/kg based on ArcGIS analysis. TP reached a mid-low level (Grade 4), averaging 0.51 g/kg, with most regions in the 0.4–0.6 g/kg range on the spatial map. Urban forest soil pH ranged from 5.43 to 8.89, and soil bulk density ranged from 1.11 to 1.62 g/cm^3.

Spatial distribution of the Nemorow comprehensive soil fertility index (F) revealed that most urban regions fell within the 1.5–1.8 range, indicating medium soil fertility overall for Changchun City (Grade 3 in the 4-grade system). Forest type-related differences were mainly found in pH, TN, TP, and TK ($P < 0.05$). Ring road-related urban-rural gradient differences occurred in pH, SOM, and TP ($P < 0.05$), whereas administrative district-related differences were found in all studied parameters except soil bulk density, TK, and AK ($P < 0.05$). Differences among forest types followed the sequence: LF > AF = FF > RF. Among administrative districts, the sequence was: Lvyuan > Chaoyang > Nanguan > Erdao > Kuancheng. For ring road-related differences, the sequence was: 1-ring > 3-ring = 4-ring > 2-ring > outside 4-ring.

Based on these results, measures to improve urban soil in Changchun are proposed, such as loosening soil, reducing soil alkalinity, on-site litter compost cycling, N-P fertilizer addition without K addition, and using N-fixing trees with low P demand to maintain suitable soil fertility. These soil diagnosis-oriented measures could promote better development of urban forests and green spaces, and our data provide an example of urban soil fertility evaluation for improving soil-based urban vegetation ecological services for resident life.

Keywords: soil organic matter; soil N, P and K; soil physicochemical properties; soil comprehensive fertility index and grading evaluation; spatial distribution map; urban forest types

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1. Materials and Methods

1.1 Study Area

Changchun City is located between 43°05 -45°15 N and 124°18 -127°05 E in a temperate continental monsoon climate zone. The city experiences four distinct seasons with dry, windy springs; hot, humid summers; crisp autumns; and cold, long winters. The average annual temperature is 4.8°C, with extreme highs of 39.5°C and lows of -39.8°C. The urban elevation ranges from 250–350 m with flat, open terrain and 2,688 annual sunshine hours.

1.2 Soil Sampling

Soil samples were systematically selected across Changchun using a grid method and classified by urban forest type, administrative district, and ring road gradient [9]. Forest types included roadside forest, affiliated forest (residential areas, institutional grounds, school green spaces), landscape forest (urban parks), and farmland shelterbelt forest. Administrative districts included Chaoyang, Lvyuan, Nanguan, Kuancheng, and Erdao. Ring road gradients included 1st-4th ring roads and areas outside the 4th ring. At each site, three soil samples were collected from the 0–20 cm layer under forest canopy, mixed into one composite sample, and brought to the laboratory. After air-drying, samples were sieved through a 0.25 mm mesh for analysis.

1.3 Soil Indicator Measurement

Nine soil indicators were measured: bulk density (using a cutting ring), SOM (by potassium dichromate external heating method), TN (by semi-micro Kjeldahl method), TP (by alkali fusion-molybdenum antimony colorimetry), TK (by alkali fusion-atomic absorption spectrophotometry), AN (by alkali hydrolysis diffusion method), AP (by sodium bicarbonate extraction-molybdenum blue colorimetry), and AK (by ammonium acetate extraction-atomic absorption spectrophotometry) [10].

1.4 Single Indicator Evaluation

Soil indicators were graded using the 6-grade classification from the 2nd National Soil Survey (Table 1) to evaluate SOM, TN, TP, TK, AN, AP, AK, pH, and bulk density, with comparisons across forest types, districts, and ring roads [4, 11–13].

1.5 Comprehensive Soil Fertility Evaluation

A modified Nemorow comprehensive index method was used for integrated assessment [4, 11-13]. Indicators were standardized using 2nd National Soil Survey grading criteria to eliminate dimensional differences. Standardization methods were:

When attribute values were "poor" : Fi = ci/xa (Fi   1)
When "medium" : Fi = 1 + (ci - xa)/(xc - xa) (1 < Fi   2)
When "good" : Fi = 2 + (ci - xc)/(xp - xc) (2 < Fi   3)
When "excellent" : Fi = 3 (ci > xp)

Where Fi is the attribute coefficient, ci is the measured value, and xa, xc, xp are grading thresholds.

For bulk density, which has an optimal range of 1.14–1.26 g/cm³ for root growth, special standardization was applied: values within this range received higher Fi, while values outside received lower Fi. Specific methods followed [13].

The modified Nemorow formula was then applied:

$F = \sqrt{[(Fi\_avg^2 + Fi\_min^2)/2]}$

Where Fi_avg is the mean of all fertility indices, Fi_min is the minimum value, and n is the number of parameters. This formula emphasizes the limiting factor principle in plant growth.

1.6 Spatial Distribution Mapping

Kriging interpolation, a robust geostatistical method, was performed using ArcGIS 10.2 to map spatial distributions of soil physicochemical properties and comprehensive fertility indices. Based on 2nd National Soil Survey standards, classification ranges were established for mapping (e.g., SOM: 20-30, 30-40, >40 g/kg; pH: 6.5-7.5, 7.5-8.0, >8.0; bulk density: 1.2-1.3, 1.3-1.4, >1.4 g/cm³; comprehensive fertility index: 1.4-1.5, 1.5-1.8, >1.8).

1.7 Data Processing

Variance analysis and multiple comparisons among forest types, districts, and ring roads were conducted using JMP 10.0. Descriptive statistics and tables were generated using Excel 2010.

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2. Results

2.1 Statistical Characteristics of Soil Physicochemical Properties

Changchun urban forest soil had a pH range of 5.43-8.89 (mean 7.57, CV 9.26%). Bulk density averaged 1.38 g/cm³ (range 1.11-1.62 g/cm³, CV 6.99%). SOM averaged 34.51 g/kg (range 6.58-124.74 g/kg, CV 50.41%). TN averaged 1.37 g/kg (range 0.35-3.4 g/kg, CV 39.03%). TP averaged 0.51 g/kg (range 0.21-1.81 g/kg, CV 41.04%). TK averaged 58.7 g/kg (range 29.27-87.32 g/kg, CV 16.12%). AN averaged 133.04 mg/kg (range 28-402.5 mg/kg, CV 39.67%). AP averaged 38.47 mg/kg (range 2.83-302.65 mg/kg, CV 94.71%). AK averaged 255.85 mg/kg (range 69.99-1055.4 mg/kg, CV 55.77%) (Table 3).

2.2 Soil Physicochemical Properties Across Forest Types, Districts, and Ring Roads

Forest Types: Significant differences ($P < 0.05$) were found in pH, TN, TP, and AN, with the pattern: landscape forest > affiliated forest = farmland shelterbelt > roadside forest for most nutrients. TK and AK showed no significant differences among forest types.

Administrative Districts: All parameters except bulk density, TK, and AK showed significant differences ($P < 0.05$). SOM was highest in Lvyuan, TN highest in Erdao, TP highest in Nanguan, and AN highest in Chaoyang. The comprehensive fertility index followed: Lvyuan (1.79) > Chaoyang (1.61) > Nanguan (1.51) > Erdao (1.58) > Kuancheng (1.51).

Ring Road Gradients: Except for pH, SOM, and TP, most nutrients showed no significant differences across ring roads. However, fertility index and SOM exhibited a decreasing trend from inner to outer rings. The pattern was: 1-ring (1.69) > 3-ring = 4-ring (1.66) > 2-ring (1.64) > outside 4-ring (1.58) (Table 4 , Table 5).

2.3 Spatial Distribution of Soil Properties and Comprehensive Fertility Index

Spatial distribution maps (Figure 2 [Figure 2: see original paper]) revealed: - **pH:** Most areas ranged 7.5-8.0, with 6.5-7.5 concentrated in southeastern Chaoyang and Nanguan districts. - **Bulk density:** Predominantly 1.3-1.4 g/cm³, with 1.4 g/cm³ in northern and southern regions. - **SOM:** Mostly >30 g/kg, concentrated in 30-40 g/kg range. - **TN:** Mostly 1-1.5 g/kg, except small areas in northern Kuancheng district. - **TP:** Mostly 0.4-0.6 g/kg (mid-low level). - **TK:** Mostly 50-60 g/kg. - **AN:** Mostly 90-150 mg/kg. - **AP:** Mostly 20-40 mg/kg, except small areas in Chaoyang district <20 mg/kg. - **AK:** Mostly 200-300 mg/kg, with some areas >300 mg/kg. - **Comprehensive fertility index (F):** Mostly 1.5-1.8 across the city, with small areas in northern Kuancheng district at 1.4-1.5 (Figure 3 [Figure 3: see original paper]).

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3. Discussion

3.1 Soil Fertility Rating Based on 2nd National Soil Survey and Spatial Distribution

Soil organic matter is a key fertility indicator [14], significantly affected by urbanization [15]. Changchun' s average SOM of 34.51 g/kg reached Grade 2 (high level) of the 2nd National Soil Survey, with most regions concentrated in the 30-40 g/kg range. This is higher than Beijing' s Daxing District (23.7 g/kg) [16] and other cities, likely due to timely litter return from dense urban greening and organic carbon sources from high population density and domestic waste [19]. Urban soil organic carbon accumulates more readily in surface layers due to lower temperatures and reduced decomposition rates [20-21].

Total phosphorus was low (0.51 g/kg, Grade 4 mid-low level), with most regions at 0.4-0.6 g/kg, while available phosphorus was high (38.47 mg/kg, Grade 2). This pattern, also observed in Shanghai [22], reflects enhanced phosphorus availability despite low total P. Total nitrogen (1.37 g/kg) and available nitrogen (133.04 mg/kg) both reached Grade 3 or higher, with most regions meeting 2nd National Soil Survey standards. Total potassium (58.7 g/kg) and available potassium (255.85 mg/kg) were the highest grade, with most regions exceeding standard levels.

Soil pH, a comprehensive indicator of chemical properties affecting nutrient availability [23], averaged 7.57, with most soils in the 7.5–8.0 range (slightly alkaline). This aligns with studies in other Chinese cities [16, 26] and results from construction debris and anthropogenic disturbances during urbanization [15, 19]. Soil bulk density, a critical physical property reflecting soil compactness and porosity, averaged 1.38 g/cm³, with most areas at 1.3–1.4 g/cm³—higher than the optimal 1.14–1.26 g/cm³ range for plant growth [13, 15, 26–27]. This compaction is attributed to high population density and trampling, consistent with urban soil studies [12–13, 15].

3.2 Variations and Limiting Factors Among Forest Types, Districts, and Ring Roads

Different urban forest types, districts, and ring roads exhibit distinct ecological functions and landscape characteristics. Significant differences among forest types in pH, TN, TP, and TK ($P < 0.05$) showed the pattern: landscape forest > affiliated forest = farmland shelterbelt > roadside forest. Landscape forests (urban parks) had the highest comprehensive fertility index (1.65), attributed to protective facilities, dedicated maintenance staff, and greater management investment [28–30]. Roadside forests had the lowest fertility (1.55) due to poor management and excessive trampling [31].

Administrative districts showed significant differences in all parameters except bulk density, TK, and AK ($P < 0.05$). Southwestern districts (Lvyuan, Chaoyang, Nanguan) had higher fertility than northeastern districts (Erdao, Kuancheng). Ring road gradients showed significant differences only in pH, SOM, and TP, with a decreasing fertility trend from inner to outer rings (1-ring: 1.69 > 3-ring = 4-ring: 1.66 > 2-ring: 1.64 > outside 4-ring: 1.58). This pattern reflects anthropogenic impacts like vehicle emissions and waste pollution that may not necessarily reduce fertility [32], but rather increasing management challenges with expanding area.

The modified Nemorow formula highlights limiting factors through the minimum Fi value. Across forest types, districts, and ring roads, TP, TN, and bulk density consistently showed the lowest Fi values, identifying them as primary limiting factors for soil fertility in Changchun' s urban forests.

3.3 Management Recommendations for Urban Forest Green Spaces

Based on these findings, targeted measures are recommended to improve soil quality:

Biological measures: On-site litter composting, planting nitrogen-fixing legumes to enhance phosphorus availability [33], and selecting native species adapted to local soil conditions [34].

Management measures: Soil loosening, installing protective barriers to prevent trampling, dedicated maintenance staff, preventing waste contamination, controlling potassium levels, and applying nitrogen-phosphorus organic fertilizers.

These soil diagnosis-oriented strategies can enhance urban forest quality and ecological services.

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4. Conclusion

Changchun' s urban forest green space soils show: - High SOM, TN, AN, AP, TK, and AK, reaching Grade 3 or higher of the 2nd National Soil Survey - Low TP and high bulk density as main limiting factors - Spatially, most areas have comprehensive fertility indices of 1.5–1.8 (medium fertility) - Fertility patterns vary significantly by forest type (LF > AF = FF > RF), district (southwest > northeast), and ring road (inner > outer) - Management should focus on biological and anthropogenic regulation to improve soil quality, particularly addressing TP deficiency and compaction

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