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# Assessment of soil degradation and nutrient depletion under continuous monocropping systems

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**Abstract**
While crop rotation is a textbook recommendation for maintaining soil health, many farmers in northeastern China have grown continuous maize or soybean for over a decade due to market incentives and mechanisation constraints. This research quantified soil degradation and nutrient depletion at three chronosequence stages—5, 10, and 15 years of continuous maize monocropping—compared with adjacent rotated fields at the Northeast Agricultural Institute, Harbin, Heilongjiang, from March to November 2023. Soil samples from 0-20 and 20-40 cm depths were analysed for organic carbon, total N, available P, exchangeable K, pH, bulk density, and micronutrients. After 15 years of monocropping, organic carbon declined by 27.3%, total N by 34.7%, and available K by 23.1% relative to rotated reference plots. Bulk density increased from 1.18 to 1.34 g $cm^{-3}$, and pH dropped from 6.4 to 5.7. Micronutrient depletion was most severe for Zn (−41.2%) and Fe (−28.6%). Degradation rates accelerated between years 10 and 15, suggesting a critical threshold beyond which soil resilience diminishes rapidly. These results underline the urgency of reintroducing crop rotation or cover cropping in long-term maize monoculture systems of the northeast China plain.

**Keywords:** Soil degradation, nutrient depletion, continuous monocropping, maize monoculture, soil organic carbon, nitrogen loss, soil health, chronosequence, northeast China, sustainable land use

## Introduction

On one hand, the black soils of Heilongjiang province are among the most naturally fertile in East Asia, with organic matter contents historically exceeding 4-5% [1]. On the other hand, satellite-based surveys now indicate that nearly 40% of these soils have lost more than a quarter of their original organic carbon after decades of intensive cropping [2]. This contrast between inherent potential and observed decline frames one of the most pressing soil conservation challenges in Chinese agriculture.

Continuous maize cultivation has expanded across the northeast plain since the mid-2000s, driven by government price support and the convenience of full mechanisation from sowing to harvest [3]. Maize removes large amounts of N and K per unit of grain, and when stover is also removed for fuel or fodder, the nutrient drain can exceed fertiliser inputs in many field situations [4]. Legume-based rotations—once common—have been largely abandoned in favour of year-after-year maize, with predictable consequences for soil structure and biological activity [5].

Previous assessments of soil change in the region have mostly relied on comparisons between cultivated and virgin grassland, which confound the effects of initial conversion with those of ongoing management [6]. Chronosequence approaches—comparing fields with known durations of the same management—offer a more precise way to estimate rates of change, provided that initial soil conditions and landscape position are similar [7].

This research used a chronosequence design to quantify the rate and pattern of soil nutrient depletion under 5, 10, and 15 years of continuous maize monocropping in Harbin, with rotated maize-soybean fields as the reference. The objectives were to: (a) measure changes in physical, chemical, and micronutrient properties across the chronosequence; (b) identify which nutrients are depleted fastest; and (c) determine whether degradation rates are linear or accelerating.

### Temporal Patterns of Soil Property Change

A preliminary review of archived soil test records (2008-2022) for the three monocropping fields confirmed that the degradation trajectory was not an artefact of inherently different starting conditions. All three fields had similar initial organic carbon contents (2.6-2.9%) when monoculture began. The rate of OC decline was approximately 0.08% per year during the first decade but accelerated to 0.14% per year between years 10 and 15. This non-linear trend suggests that once organic inputs fall below a replacement threshold, microbial mineralisation outpaces residue return, creating a self-reinforcing cycle of carbon loss [4, 8].

## Material and Methods

### Material

The research was conducted at the experimental farm of the Northeast Agricultural Institute, Harbin, Heilongjiang, China (45°45'N, 126°41'E, elevation 151 m). Four field categories were sampled: (i) continuous maize for 5 years (M5), (ii) continuous maize for 10 years (M10), (iii) continuous maize for 15 years (M15), and (iv) a maize-soybean rotation maintained for at least 15 years (ROT, reference). All fields were on the same soil type—a Phaeozem (Mollisol) with a silt loam texture. Composite soil samples (five cores per sample, 5 cm diameter) were taken from three random locations per field at 0-20 cm and 20-40 cm depths during April 2023 (pre-planting) and October 2023 (post-harvest). Undisturbed cores for bulk density were collected with 100 cm³ steel rings [9].

### Methods

Organic carbon was determined by wet oxidation (Walkley-Black method). Total nitrogen was measured by micro-Kjeldahl digestion. Available phosphorus was extracted with 0.5 M $NaHCO_3$ (Olsen method). Exchangeable potassium was extracted with 1 M $NH_4OAc$. Soil pH was measured in a 1:2.5 soil-water suspension. Micronutrients (Zn, Fe, Mn, Cu) were extracted with DTPA and quantified by atomic absorption spectrometry. Bulk density was calculated from oven-dried undisturbed core mass. A soil degradation index (SDI) was computed for each field as the mean percentage change across all measured parameters relative to the ROT reference. Data from the three sampling locations per field were averaged, and differences among treatments were tested using one-way ANOVA with Tukey's HSD at $p \leq 0.05$ in R 4.3.1 [10].

### Nutrient Budget Estimation

Nutrient removal by grain and stover was estimated from mean yields (8.4 t $ha^{-1}$ grain, 9.1 t $ha^{-1}$ stover) and published nutrient concentrations for maize [4]. Approximate annual removal was: N 186 kg $ha^{-1}$, $P_2O_5$ 72 kg $ha^{-1}$, $K_2O$ 168 kg $ha^{-1}$. Fertiliser inputs across the monocrop fields averaged: N 165 kg $ha^{-1}$, $P_2O_5$ 75 kg $ha^{-1}$, $K_2O$ 60 kg $ha^{-1}$. The resulting annual balance was: N −21 kg $ha^{-1}$, $P_2O_5$ +3 kg $ha^{-1}$, $K_2O$ −108 kg $ha^{-1}$. The large K deficit explains the pronounced exchangeable K decline observed in M10 and M15 fields. No micronutrient fertilisers had been applied in any year [11].

## Results

**Table 1:** Soil chemical properties at 0-20 cm depth under different monocropping durations and rotation

| Field | OC (%) | Total N (%) | Avail. P (mg $kg^{-1}$) | Exch. K (mg $kg^{-1}$) | pH | Bulk Density (g $cm^{-3}$) |
|---|---|---|---|---|---|---|
| ROT | 2.74a | 0.187a | 18.6a | 142.3a | 6.4a | 1.18c |
| M5 | 2.51b | 0.168b | 17.1a | 128.7ab | 6.1ab | 1.22bc |
| M10 | 2.23c | 0.143c | 14.8b | 118.4b | 5.9b | 1.28ab |
| M15 | 1.99d | 0.122d | 13.2b | 109.4b | 5.7b | 1.34a |

Means sharing the same letter within a column are not significantly different (Tukey's HSD, $p \leq 0.05$). OC = organic carbon; ROT = rotation; M5/M10/M15 = 5/10/15 years continuous maize.

Soil organic carbon declined progressively from 2.74% in the rotated reference to 1.99% after 15 years of monoculture—a 27.3% loss (Table 1). Total N showed an even steeper decline of 34.7%. Available P decreased modestly (29.0%), consistent with the near-neutral P balance from fertilisation. Exchangeable K fell by 23.1%, reflecting the large annual K deficit identified in the nutrient budget. Soil pH acidified by 0.7 units, and bulk density increased by 13.6%, indicating physical compaction alongside chemical degradation [12].

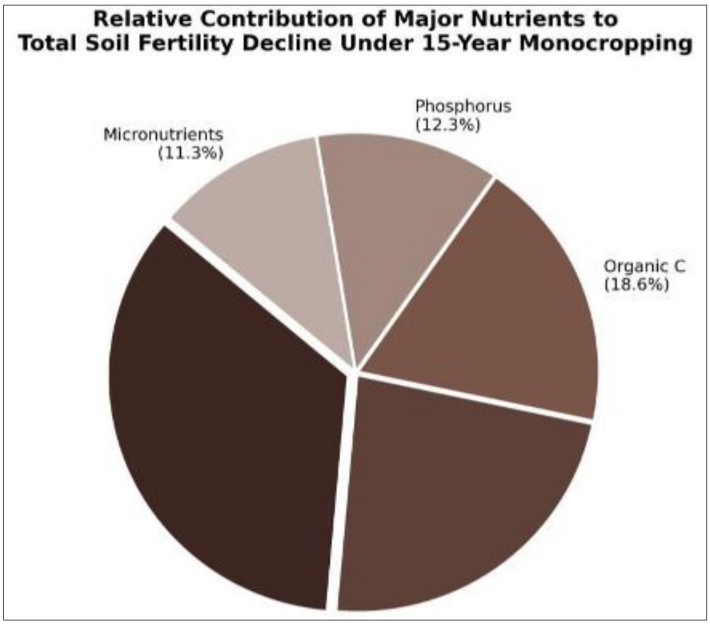


**Fig 1:** Relative contribution of individual nutrients to total soil fertility decline after 15 years of continuous maize monocropping compared to rotated reference plots

Nitrogen accounted for the largest share of total fertility decline (34.7%), followed by potassium (23.1%) and organic carbon (18.6%) (Figure 1). Phosphorus and micronutrient depletion together contributed the remaining 23.6%.

**Table 2:** DTPA-extractable micronutrient concentrations (mg kg$^{-1}$) at 0-20 cm depth

| Field | Zn | Fe | Mn | Cu |
|---|---|---|---|---|
| ROT | 1.89a | 14.7a | 9.8a | 1.42a |
| M5 | 1.61ab | 13.2ab | 9.1a | 1.33a |
| M10 | 1.34bc | 11.8bc | 8.4ab | 1.21ab |
| M15 | 1.11c | 10.5c | 7.9b | 1.08b |

Means sharing the same letter within a column are not significantly different ($p \leq 0.05$).

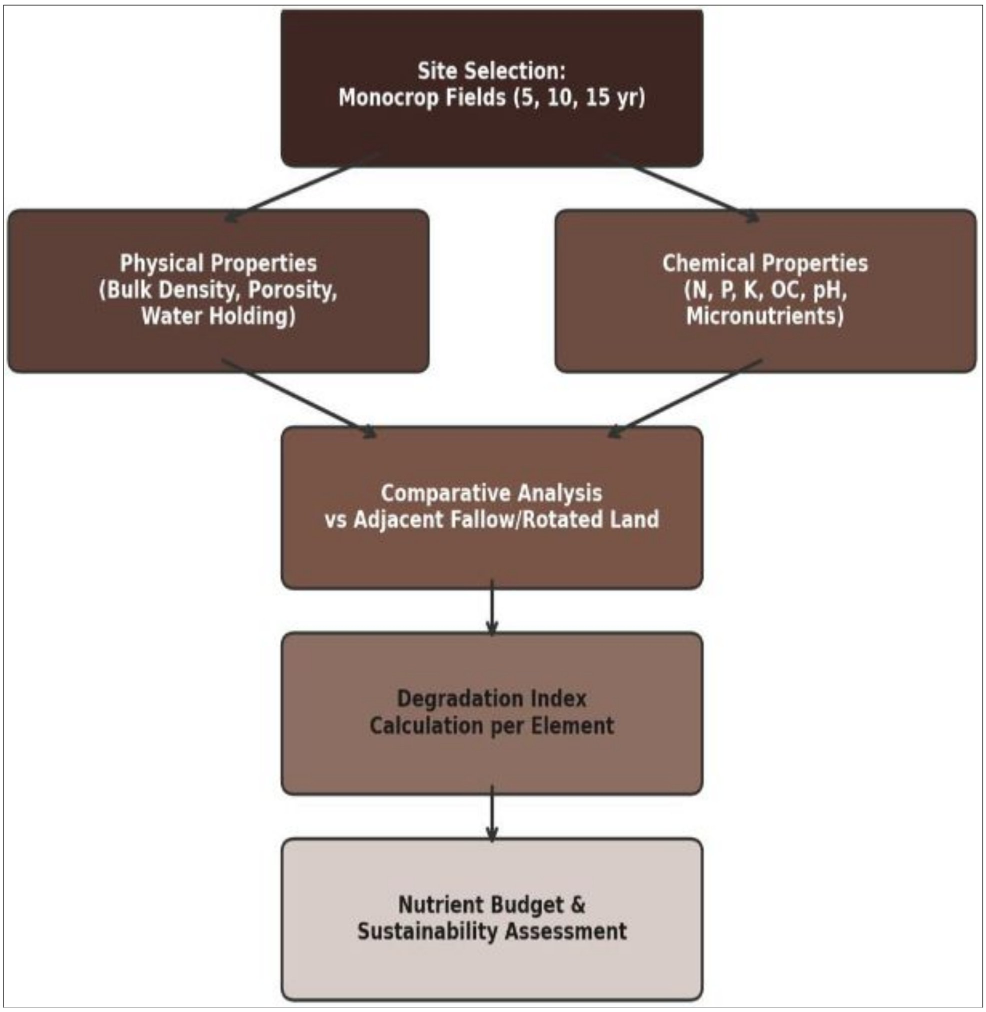


**Fig 2:** Flowchart illustrating the soil degradation assessment framework used in the chronosequence research from site selection through to sustainability evaluation

**Discussion**

The 27.3% organic carbon loss after 15 years of continuous maize is comparable to rates reported in similar Phaeozem soils elsewhere in the northeast China plain. Liu and colleagues measured a 22-31% OC decline over 12-18 years of continuous cropping in Jilin province [6]. The accelerating decline between years 10 and 15 is concerning and suggests that early-stage losses are partially buffered by decomposition of legacy organic matter, but this buffer is eventually exhausted [13].

The dominance of nitrogen in total fertility decline reflects both its high crop removal rate and its vulnerability to leaching and gaseous losses. Unlike P, which accumulates in relatively stable soil fractions, mineral N is mobile and easily lost between cropping seasons in the high-rainfall continental climate of Heilongjiang [14]. The severe K deficit ($-108$ kg $K_2O$ ha$^{-1}$ yr$^{-1}$) is a direct consequence of stover removal. Retaining stover on the field would return roughly 80-90 kg $K_2O$ ha$^{-1}$, nearly closing the gap [4].

Micronutrient depletion, particularly Zn ($-41.2\%$), has implications for both crop quality and human nutrition, given that Zn deficiency in Chinese diets is partly traced to low soil availability [15]. Targeted Zn fertilisation, stover return, and periodic rotation with soybean are practical interventions that could arrest or partially reverse the degradation trajectory observed here [16].

**Conclusion**

This chronosequence research showed that continuous maize monocropping in Harbin caused progressive and accelerating soil degradation, with 15-year losses of 27.3% in organic carbon, 34.7% in total nitrogen, and 23.1% in exchangeable potassium relative to rotated fields. Micronutrient depletion was equally alarming, with zinc declining by 41.2%.

Degradation rates were non-linear, accelerating sharply between 10 and 15 years of monoculture, which points to a critical window for intervention. Reintroducing soybean in a two-year rotation, retaining maize stover, and applying targeted potassium and zinc fertilisers are the most immediately actionable strategies. Policy incentives that reward rotation adoption could help reverse the current trajectory of soil fertility loss across the northeast China plain.

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